THE PURCELL ERUPTIVE ROCKS

G. H. Hunt

THE UNIVERSITY OF ALBERTA

THE PURCELL ERUPTIVE ROCKS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN

PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

by

GRAHAM HUGH HUNT, B.Sc., M.Sc.

EDMONTON, ALBERTA

OCTOBER, 1961

ABSTRACT

The Purcell eruptive rocks consist of an extensive accumulation of sills and spatially related altered basaltic flows in the Proterozoic formations of southwestern Alberta and southeastern British Columbia. Stratigraphic studies over the past fifty years indicate a thick succession of fine clastic sediments in the Purcell Mountains which thin markedly toward the east in the Rocky Mountains. Clastic sedimentation was apparently initiated in the west, with carbonate deposition becoming dominant in the upper and eastward extension of the Purcell System.

To the west, the sills are most abundant and thickest in the basal formations of the Purcell System. In the east, most of the sills are found in the Upper Purcell Siyeh formation, with a few thin sills in the lower and higher horizons. The sills studied in the western area are hornblende-quartz diabases. The eastern sills differ in that they contain primary pyroxene.

Two distinct areas of chloritized Purcell lavas of submarine origin are found; one in the northern part of the Lewis thrust block, the other bordering the Rocky Mountain Trench from about latitudes 49° to 50° N. In the western area two main periods of volcanism took place in the Siyeh epoch. Basaltic lavas in the Lewis thrust block are found through a wide stratigraphic interval, with the thickest accumulation of lava found at the top of the Siyeh formation. Thin, local pyroxene-bearing lavas occur in the Lewis thrust block but not in the area adjacent to the Rocky Mountain Trench.

Chemically, the western Purcell lavas may be classified as tholeiitic to olivine basalts. The eastern Purcell extrusions belong to the trachybasalt family. Normative olivine is present in both the Purcell extrusive and intrusive phases from the eastern and western areas. Differentiation index diagrams suggest a two-fold grouping of the Purcell igneous rocks, with a tholeiitic basalt and its intrusive quartz diabase equivalents in the west and a more alkaline basalt in the east.

Potassium-argon data suggests that initial Purcell intrusion occurred in the west about 1500 million years ago, followed by late Purcell magmatism in the eastern and western areas about 1100 million years ago. At least two major metamorphic events, the East Kootenay orogeny, dated 750 to 850 million years, and the Coast Range orogeny, dated at 100 million years, affected the Purcell igneous rocks.

ACKNOWLEDGEMENTS

Many thanks are extended to all members of the Department of Geology, University of Alberta for their help and encouragement, but particularly to Dr. R.A. Burwash under whose patient guidance the thesis was carried out. Grateful acknowledgements are made to Dr. R.E. Folinsbee, Dr. G.B. Leech, Dr. H. Baadsgaard and Dr. F.A. Campbell for critically reading the manuscript and offering many helpful suggestions. F. Dimitrov assisted with the drafting and photography. Miss S. Baker prepared the manuscript.

The author wishes to acknowledge the financial help in the form of a graduate teaching fellowship from the International Nickel Co. The cost of the field work, preparation of the thin sections and the use of the excellent laboratory facilities were all generously provided by the Department of Geology.

TABLE OF CONTENTS

	Page
ABSTRACT	i
ACKNOWLEDGEMENTS	iii
CHAPTER I - INTRODUCTION	1
PROBLEM	1
FIELD WORK	4
LABORATORY WORK	4
PREVIOUS WORK	6
CHAPTER II - REGIONAL PRECAMBRIAN GEOLOGY	11
INTRODUCTION	11
LEWIS SERIES	13
Distribution and Thickness	13
Description of Formations	16
Waterton Formation	16
Altyn Formation	17
Appekunny Formation	18
Grinnell Formation	18
Siyeh Formation	19
Sheppard Formation	20
Kintla Formation	21
GALTON SERIES	21
Description of Formations	22

Page

Altyn Formation -- 22

Hefty Formation -- 22

MacDonald Formation ------------------------------------ 22

Wigwam Formation --------------------------------------- 22

Siyeh Formation -- 23

Gateway Formation -------------------------------------- 23

Phillips Formation ------------------------------------- 23

Roosville Formation ------------------------------------ 24

PURCELL SYSTEM --- 24

Description and Correlation of Formations ------------------- 25

Fort Steele Formation ---------------------------------- 25

Aldridge Formation ------------------------------------- 26

Creston Formation -------------------------------------- 29

Kitchener Formation ------------------------------------ 30

Siyeh Formation -- 30

Gateway Formation -------------------------------------- 32

Dutch Creek Formation ---------------------------------- 33

Mount Nelson Formation --------------------------------- 33

WINDERMERE SYSTEM -- 34

Description and Correlation of Formations ------------------- 34

Toby Conglomerate Formation ---------------------------- 34

Irene Volcanic Formation ------------------------------- 35

Horsethief Creek Formation ----------------------------- 36

SUMMARY AND CONCLUSIONS -------------------------------------- 36

Page

CHAPTER III - EXTRUSIVE PHASE ---------- 39

INTRODUCTION ---------- 39

LEWIS SERIES ---------- 41

Glacier National Park Area ---------- 41

Waterton National Park Area ---------- 44

Ruby Ridge and Blakiston Brook Area ---------- 46

Petrography of the Ruby Ridge Section ---------- 48

Petrography of the Blakiston Brook Section ---------- 48

Petrography of the Contact Rocks ---------- 51

Mount Rowe Section ---------- 51

Castle River Area ---------- 54

Castle River Section ---------- 56

GALTON SERIES ---------- 57

Roosville Section ---------- 59

PURCELL SERIES ---------- 61

Type Section Area ---------- 61

Cranbrook Area ---------- 63

Gold Creek Section ---------- 66

Skookumchuck Creek Section ---------- 69

Lussier River Section ---------- 70

CHAPTER IV - INTRUSIVE PHASE ---------- 74

INTRODUCTION ---------- 74

LEWIS SERIES ---------- 74

Glacier Park Area ---------- 74

Petrography of the Logan Pass Sill ---------- 76

Page

Waterton National Park Area ---------------------------------- 77

Petrography of the Lake Alderson Sill ------------------ 78

Petrography of the Contact Rocks ---------------------- 79

PURCELL SERIES --- 79

Dykes -- 79

Kingsgate, B.C. -- 80

Petrography of Arrow Creek Section -------------------- 80

Irishman Creek, B.C. -- 82

Petrography of the Irishman Creek Contact Rocks --------- 87

Cranbrook Area -- 89

Petrography of the Dipper Lake Sill -------------------- 91

Hellroaring Creek, B.C. ------------------------------------ 94

Petrography -- 94

CHAPTER V - CHEMICAL COMPOSITION ---------------------------- 96

INTRODUCTION -- 96

COLLECTION AND PREPARATION ---------------------------------- 96

RESULTS -- 99

INTERPRETATION -- 99

Definitions -- 99

Discussion --- 102

DIFFERENTIATION INDEX -- 108

Introduction --- 108

Comparison -- 109

Conclusions --- 111

Page

CHAPTER VI - PHYSICAL AGE DETERMINATIONS ---------------------------- 114

INTRODUCTION -- 114

COLLECTION AND PREPARATION OF SAMPLES ------------------------------ 114

RESULTS -- 117

INTERPRETATION AND COMPARISON ------------------------------------ 120

Western Area -- 120

Irishman Creek -- 120

St. Mary Lake Area, B.C. -------------------------------- 121

Rocky Mountain Trench Area ------------------------------ 124

Eastern Area -- 124

Glacier Park, Montana ----------------------------------- 124

Waterton Park, Alberta ---------------------------------- 125

Southern Area -- 126

SUMMARY -- 126

CHAPTER VII - CONCLUSIONS -- 129

SELECTED BIBLIOGRAPHY --- 135

APPENDIX A - Location of Samples and Thin Sections --------------- I

Page

LIST OF TABLES

Table 1. Nomenclature and thickness of Proterozoic Formations ---- 15

Table 2. Modal Analyses of Present Study on Basic Igneous Rocks -- 95

Table 3. Composition of Purcell Igneous Rocks ------------------- 97

Table 4. Comparison of Compositions ----------------------------- 103

Table 5. Data on Samples Dated in Present Study ----------------- 116

LIST OF FIGURES

Figure 1. Area of Study --- 2

Figure 2. Regional Geology -------------------------------------- 12

Figure 3. Distribution of Irene Volcanics, Kaslo Greenstone and Purcell Lava ------------------------------------ 40

Figure 4. Geologic Sketch map, Logan Pass Area, Montana --------- 42

Figure 5. Geologic Sketch Map, Waterton Lake Area, Alberta ------- 45

Figure 6. Ruby Ridge Section ------------------------------------ 47

Figure 7. Blakiston Brook Section ------------------------------- 49

Figure 8. Mt. Rowe Section -------------------------------------- 52

Figure 9. Geologic Sketch Map, Castle River Area, Alberta -------- 55

Figure 10. Roosville Section ------------------------------------- 58

Figure 11. Gold Creek Section ------------------------------------ 65

Figure 12. Skookumchuck Creek Section ---------------------------- 68

Figure 13. Lussier River Section --------------------------------- 71

Figure 14. Distribution of Studied Purcell Eruptive Rocks --------- 73

Figure 15. Arrow Creek Section ----------------------------------- 81

Figure 16. Irishman Creek Section -------------------------------- 83

Figure 17. Petrographic Variation in Irishman Creek Sill ---------- 86

Page

Figure 18. Geologic Sketch Map, St. Mary Lake, B.C. --------------- 90

Figure 19. Dipper Lake Section -------------------------------------- 92

Figure 20. MgO-FeO-Alkalies Diagram for Purcell analysed Rocks ---- 107

Figure 21. Variation Diagrams for Purcell Rocks ------------------- 113

Figure 22. Separation of Age Date Minerals ------------------------ 115

Figure 23. Interpretation of Dated Samples ------------------------ 118

Figure 24. Distribution of Dated Samples -------------------------- 119

Figure 25. Location of Samples ------------------------------------- II

LIST OF PLATES

Plate 1. Photographs of Hand Specimens --------------- facing page X

Plate 2. Photographs of Hand Specimens --------------- facing page XI

Plate 3. Photomicrographs of Thin Sections ----------- facing page XII

Plate 4. Photomicrographs of Thin Sections ----------- facing page XIII

Plate 5. Photomicrographs of Thin Sections ----------- facing page XIV

Plate 6. Photomicrographs of Thin Sections ----------- facing page XV

CHAPTER I - INTRODUCTION

PROBLEM

In 1957 and 1958, a study was made of the Purcell Sills that are found near St. Mary Lake, B.C. (Hunt, 1958). A late Precambrian age of 600 million years was assigned to these rocks, which were classified as deuterically altered quartz diabases. On the basis of the initial work, and on the rapidly evolving methods of physical age determination, a broader investigation into the Purcell igneous rocks seemed warranted. The present study is concerned with the temporal and spatial relations of the extrusive and intrusive basic igneous rocks to each other and to their surrounding rocks. The area to be covered, bounded approximately by latitudes 49° to 50° and longitudes 114° to 116°, is shown in Figure 1.

The extrusive rocks that are considered in this thesis are the highly altered, basaltic lavas found near the top of the Siyeh formation. These flows were named the Purcell Lava formation by Daly (1912) because the maximum known thickness is found in the Purcell Mountains. He used this lava as the main stratigraphic marker in correlating the late Precambrian sedimentary rocks along the International Boundary from the Clark Range of the Rocky Mountains to the McGillivray Range of the Purcell Mountains. The writer is unaware of any other regional petrologic or stratigraphic study of the Purcell lava since Daly's work in 1912.

The intrusive rocks which are spatially associated with the Purcell lava, but not strictly contemporaneous, have been given various names such as Moyie Sills (Daly, 1912), Purcell Sills (Schofield, 1915),

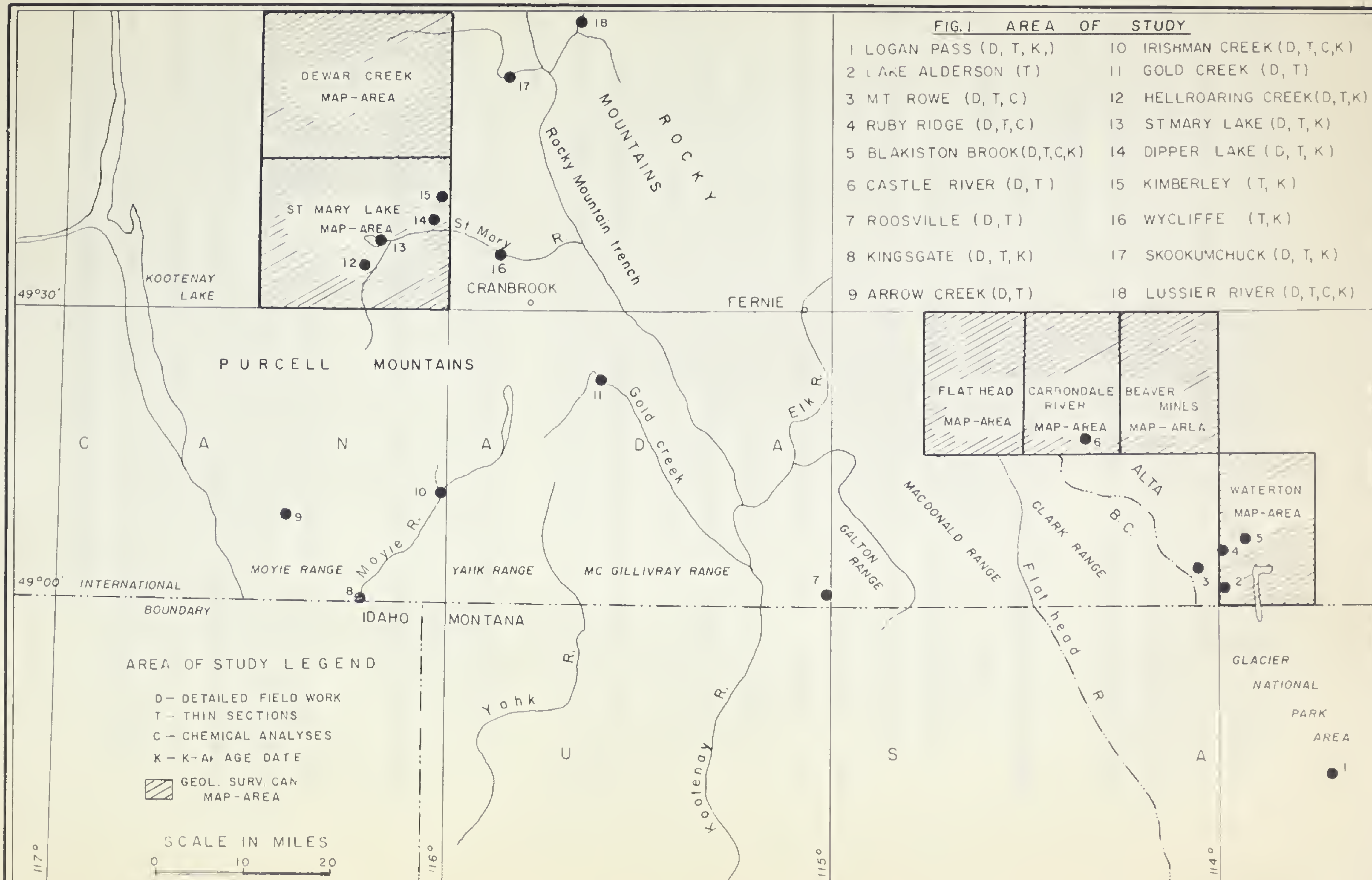


FIG. I AREA OF STUDY
1 LOGAN PASS (D, T, K,)
2 LAKE ALDERSON (T)
3 MT ROWE (D, T, C)
4 RUBY RIDGE (D, T, C)
5 BLAKISTON BROOK (D, T, C, K)
6 CASTLE RIVER (D, T)
7 ROOSVILLE (D, T)
8 KINGSGATE (D, T, K)
9 ARROW CREEK (D, T)
10 IRISHMAN CREEK (D, T, C, K)
11 GOLD CREEK (D, T)
12 HELLROARING CREEK (D, T, K)
13 ST MARY LAKE (D, T, K)
14 DIPPER LAKE (D, T, K)
15 KIMBERLEY (T, K)
16 WYCLIFFE (T, K)
17 SKOOKUMCHUCK (D, T, K)
18 LUSSIER RIVER (D, T, C, K)
DEWAR CREEK MAP-AREA
ST MARY LAKE MAP-AREA
ROCKY MOUNTAINS
Rocky Mountain trench
St Mary R
CRANBROOK
FERNIE
KOOTENAY LAKE
49°30'
PURCELL MOUNTAINS
Gold creek
Elk R
FLAT HEAD MAP-AREA
CARBONDALE RIVER MAP-AREA
BEAVER MINES MAP-AREA
WATERTON MAP-AREA
ALTA
B.C.
CANADA
Moyie R.
MOYIE RANGE
YAHK RANGE
MC GILLIVRAY RANGE
GALTON RANGE
MACDONALD RANGE
CLARK RANGE
Flat head R
49°00' INTERNATIONAL BOUNDARY
IDAHO
MONTANA
Yahk R.
Kootenay R.
GLACIER NATIONAL PARK AREA
USA
AREA OF STUDY LEGEND
D – DETAILED FIELD WORK
T – THIN SECTIONS
C – CHEMICAL ANALYSES
K – K-Ar AGE DATE
GEOL. SURV. CAN MAP-AREA
SCALE IN MILES
0 10 20
117°
116°
115°
114°

Purcell Intrusives (Rice, 1941), and Moyie Intrusions (Reesor, 1957). These intrusions, which are dominantly in the form of sills, are found most abundantly in the older Precambrian formations of the Purcell series (Purcell Mountains) but occur in nearly all the formations of the Lewis series (Rocky Mountains).

In the Purcell Mountains, the Moyie Intrusions are most abundant and thickest in the area extending from Kingsgate to St. Mary Lake (Figure 1). The Purcell lavas are exposed on the east flank of the Purcell Mountains and in the adjacent fault blocks of the Rocky Mountains. Daly (1912), Schofield (1915) and Rice (1937) thought that these intrusions were genetically related to the Purcell lava. However, Rice (1941) and more recent workers of the Geological Survey of Canada have found similar sills occurring in formations that are younger than the Purcell lava. There are three basic volcanic formations (the Purcell lava, the Irene volcanics of Precambrian age, and the Kaslo greenstones of Triassic age) in the area which may or may not be cogenetic with these intrusions.

In the Lewis and Clark ranges of the Rocky Mountains there are numerous Precambrian basic intrusive rocks, which are thinner, fewer in number and mineralogically different than the sills exposed in the Purcell mountains.

In the thesis area, almost all the sediments, which enclose the basic igneous intrusions, are mapped as Precambrian. If the intrusive rocks belonged to several igneous periods, it would not be possible to determine accurately the age relations of these intrusions in the field, unless there were two intrusions in contact or if some intrusions were older than a structural disturbance and others were younger.

FIELD WORK

Detailed mapping and sampling of the Purcell lava and sills at a number of localities was undertaken with the hope of finding critical field relations. The main objectives of the field work were:

(1) To sample over a wide geographic area for petrologic, chemical and stratigraphic correlation of the lavas and the sills.

(2) To find unaltered Purcell lava in order to determine its original composition and perhaps its subsequent history.

(3) To find a sill in the Purcell mountains which contains primary pyroxenes.

(4) To obtain fresh rock samples with well exposed relations to surrounding rock units which could be dated by the potassium-argon method.

(5) To find direct evidence of the relative ages of the lavas and the sills.

LABORATORY WORK

About 500 hand specimens were collected and examined from the thesis area. The sample numbers, thin section numbers (225) and locations of the samples are given in appendix A.

The methods used in this study to determine the properties of the minerals were based on well-established procedures of optical mineralogy.

Index of refraction measurements were made on most of the main minerals, as described by G.D. Olcott (1960). The mineral grains were separated from the crushed hand specimen or were removed from the thin section with the use of a sharp knife. The grains are then mounted in a gelatin compound and with the aid of Schillabers Certified oils, the indices are determined by the standard Becke line test.

Modal analyses were made with an automatic point-counting mechanical stage. About 500 points were counted for each thin section. A visual estimate of the modal per cent was given for most of the extrusive rocks because of their highly altered condition.

Optic Angle and Extinction Angle measurements were done with the aid of a 4-axis Universal Stage on many of the main minerals such as feldspars, pyroxenes and amphiboles. A modified Rittman zone method was used to determine the An content of the plagioclase feldspars. Fedorow's curves were used for the optic angle measurements and Kennedy's curves were used for the plagioclase extinction angles. Staining techniques, described by Hayes and Klugman (1959), were used to distinguish the potassium feldspar from the plagioclase feldspar.

Chemical analyses were done on five samples of the Purcell igneous rocks. Three samples were collected from Mount Rowe, Ruby Ridge and Blakiston Brook in Waterton Park, Alberta. The other two samples were collected from Irishman Creek and Lussier River in British Columbia. All chemical analyses were made by A. Stelmach of the Department of Geology, University of Alberta.

Physical age determinations were done by Dr. H. Baadsgaard of the Department of Geology, University of Alberta on 16 samples from the Purcell terrain.

PREVIOUS WORK

G.I. Finlay (1902) was probably the first observer to fully describe the Purcell igneous rocks found in the Waterton-Glacier National Parks area. He grouped them into two rock units, an intrusive diorite and an extrusive diabase. He listed the mineralogy of both rock types which occur in the Siyeh limestone of the Lewis series.

R.A. Daly (1912) named and mapped the Purcell igneous rocks exposed along the International Boundary from the Waterton Park area to the Purcell mountains. He gave detailed descriptions, optical data and chemical analyses of both the intrusive and extrusive rocks. He referred to the sills at Kingsgate, B.C. as the Moyie Sills and ascribed the "granitic" parts of these sills to magmatic differentiation. He emphasized the fact that the Purcell lava is exposed in the Lewis, Clarke, Galton and McGillivray ranges, but missing in the central area of the MacDonald range.

S.J. Schofield (1915) mapped and described the intrusive and extrusive Purcell phases in the Cranbrook area. He worked in detail on five sills which are exposed north of St. Mary Lake, B.C. and discussed the possible origin of the "granitic" rock in these sills. He gave detailed descriptions of the Purcell lava in the McGillvray range. The similarity of composition between the sills and lava was pointed out by Schofield and he concluded they were contemporaneous and of Precambrian age.

L.D. Burling (1916) described ellipsoids and pillows in the Purcell lavas at two locations in Glacier National Park, Montana. He concluded that the lavas which are found on Mt. Sheppard and Mt. Grinnell, Montana, must have been subaqueous flows.

A.E. Jure (1929) studied a drill core of a thick sill (600 feet) exposed near the Sullivan mine in British Columbia. He made a number of chemical analyses of these rocks. Based upon this data and detailed microscopic work he concluded that the upper and more acidic phase of the sill may have been formed by magmatic differentiation.

A.L. Anderson (1930) worked on Precambrian sills of the Clark Fork District, Montana which mineralogically resemble the Purcell sills. He noted that some of this sill material is found as pebbles in late Paleozoic rocks (Sandpoint conglomerate) in Idaho.

M.A. Fenton and C.L. Fenton (1937) summarized the sequence of igneous events in the Waterton-Glacier National Parks area. They indicated that there were at least three periods of extrusion in late Precambrian time. Basaltic flows are described in the Grinnell, Siyeh and Kintla formations of the Lewis series. The extrusion in the Siyeh formation is called the Purcell lava.

H.M.A. Rice (1937, 1941) described the lava and the intrusive rocks in the Cranbrook map-area and in the Nelson map-area. He gave optical data on the main constituents of these rocks in both publications. He pointed out that in most cases the "granitic" rock of Daly and Schofield, was metamorphosed sediments along the margins of the sills. In 1937, he presented indirect evidence to support the conclusion of

Daly and Schofield that the Purcell sills and the Purcell lava are related in the Cranbrook area. However, after mapping the Nelson area (1941), he stated the following observations which are largely concerned with the time and spatial relationships of the Purcell igneous rocks. These observations (Rice, 1941, p. 27) are quoted because many of the problems which perplexed Rice are pertinent to this study.

(1) "No direct evidence has yet been obtained of the age of the Purcell intrusives except that they are older than the Mesozoic granitic intrusives".

(2) "Sills and dykes indistinguishable in the field or laboratory occur all through the lower and upper Purcell. Sills and dykes closely resembling those in the Purcell also occur through the Windermere, but have been so sheared that the identity of compositon cannot be established."

(3) "The largest sills occur in the Aldridge formation and the sills are progressively smaller in the succeeding formations. Sills 100 to 300 feet thick however occur as high as the Mount Nelson formation."

(4) "The sills appear to have suffered all the deformation to which the sediments have been subjected."

(5) "Careful search both by the writer (Rice) and J.F. Walker (1927) has failed to reveal any pebbles of the Purcell intrusive in either the Toby or Cranbrook conglomerates. On the other hand, no Purcell intrusives have been seen to intrude either of these formations."

(6) "There are three volcanic formations to any of which all or part of the Purcell intrusives may be related. These are the Purcell lava in the Siyeh formation, the Precambrian Irene volcanic formation, and the volcanic rocks in the Kaslo series of Triassic age."

(7) "A small stock of ultrabasic rock occurs close to the edge of the White Creek batholith near Dewar Creek. .... The age of this body is not known except that it cuts the Creston and is cut by granitic dykes."

J.E. Reesor (1958, p. 31) described more fully this ultrabasic rock in the Dewar Creek map area.

C.O. Swanson and H.C. Gunning (1945) published on the geology near the Sullivan Mine, B.C. They gave a description of the Purcell sill which is associated with the ore deposits.

R. Gibson (1948) reported Precambrian sills in the Libby Quadrangle, Montana which are correlated to the Purcell sills. He described and listed the mineralogy of these sills which are not found in rocks that are younger than Siyeh equivalents.

H.C. Gunning (1954) discussed the occurrences of igneous rocks in the southern Rockies of Canada which included the Purcell igneous rocks.

B. Scott (1954) worked on the Sullivan Mine sill and suggested the possible genetic relation of the sill to the ore deposits. He concluded that the mineralization could either be Precambrian or Cretaceous in age.

Recent publications by officers of the Geological Survey of Canada on the occurrence of the Purcell lava and sills are listed below:

G.B. Leech (1957) St. Mary Lake, B.C., Map 15-1957

__________ (1958a) Fernie, B.C., Map 20-1958

__________ (1958b) Canal Flats, B.C., Map 24-1958

__________ (1959) The Southern Part of the Rocky Mountain Trench C.I.M.M. Bull., Vol. LXII, pp. 152-172.

__________ (1960) Fernie, B.C., Map 11-1960

J.E. Reesor (1953) Findlay Creek, B.C., Map 34-1953

____________ (1958) Dewar Creek, B.C., Map 1053 A - 1958

C.P. Ross (1959) worked in the Glacier Park area and mapped both the lavas and the sills as separate rock units. The farthest south lava exposure which he called the Purcell basalt is shown near Swiftcurrent Pass, Montana. The mineralogy of the sills and the occurrences of the dykes are given. The sills are confined largely to the Siyeh formation, occurring near a distinctive algal zone.

CHAPTER II - REGIONAL PRECAMBRIAN GEOLOGY

INTRODUCTION

The stratigraphy of the Proterozoic rocks found associated with the Purcell eruptive rocks is based largely on the supposition that the Purcell basaltic lavas occur everywhere at, or near, the same horizon (Reesor, 1957a). The dominant map units in Figure 2 (modified after G.B. Leech, 1959) are Late Precambrian sedimentary rocks. A detailed discussion of these rocks, with emphasis on distribution, thickness, lithology, metamorphism and correlation of the individual formations, is warranted because of their close relationship with the Purcell igneous rocks.

Since the continuity of the Proterozoic rocks has not been established by mapping in this region, a detailed lithologic description of each formation and a comparison of the sequence of these formations in different stratigraphic sections is required for correlation purposes.

At the International Boundary, Precambrian sedimentary rocks are exposed in all ranges (Lewis, Clark, MacDonald and Galton) of the Rocky Mountains and also in the ranges (McGillivray, Yahk and Moyie) of the Purcell Mountains. Daly (1912) divided this conformable, gradational, thick and fine-grained succession of dominantly clastic rocks into three units called the Lewis Series, the Galton Series and the Purcell Series. He used the name Lewis Series for the rocks of the Lewis and Clark ranges, and Galton Series for the rocks of the MacDonald and Galton ranges and the Purcell Series for the rocks of the entire Purcell Mountains. Officers of the Geological Survey of Canada now refer to the Purcell Series as the Purcell System.

Figure 2. Regional Geology (after Leech, 1959).

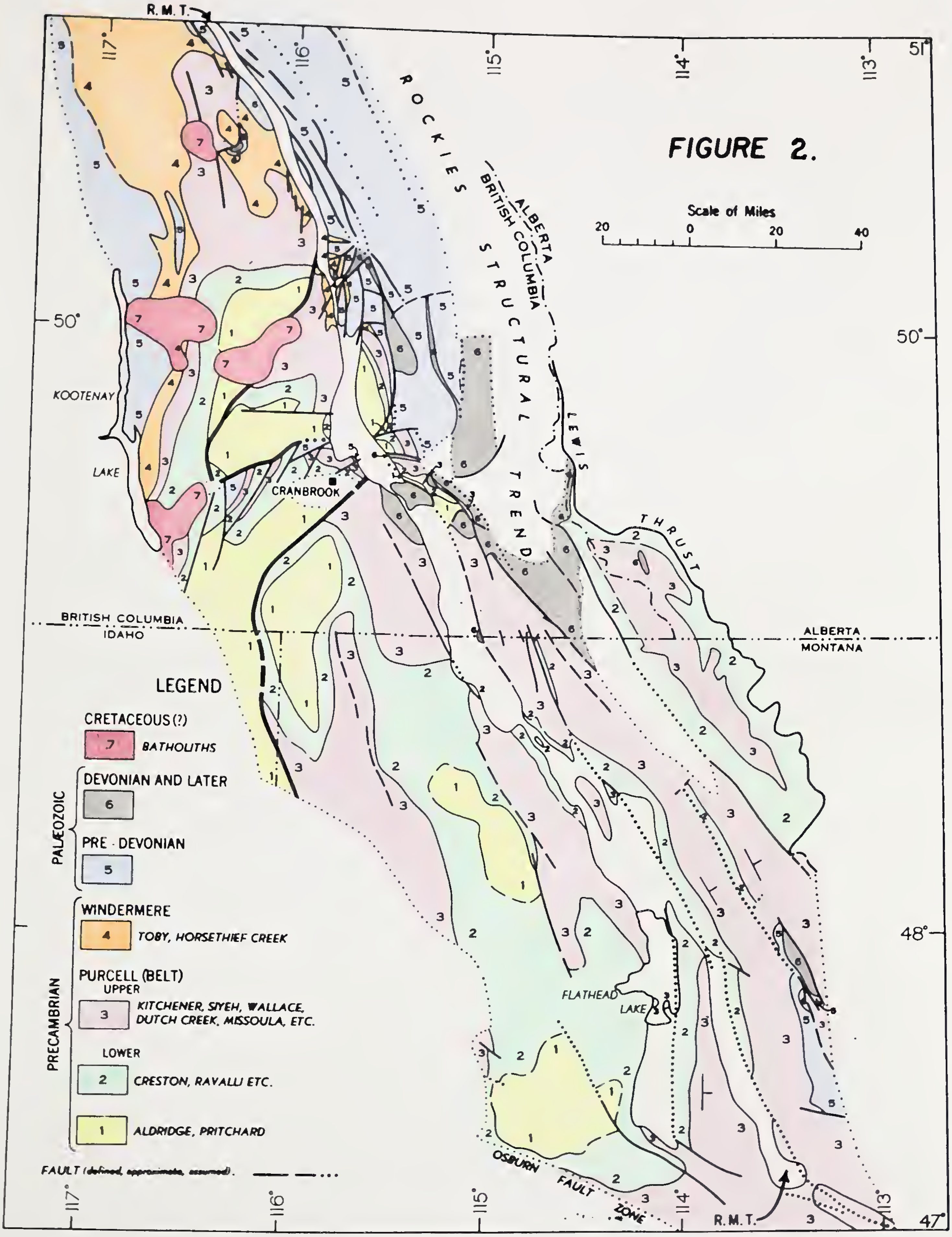


FIGURE 2.
Scale of Miles
20 0 20 40
ROCKIES STRUCTURAL TREND
ALBERTA
BRITISH COLUMBIA
LEWIS THRUST
R.M.T.
KOOTENAY LAKE
CRANBROOK
BRITISH COLUMBIA
IDAHO
ALBERTA
MONTANA
FLATHEAD LAKE
OSBURN FAULT ZONE
LEGEND
CRETACEOUS (?)
7 BATHOLITHS
PALÆOZOIC
DEVONIAN AND LATER
6
PRE · DEVONIAN
5
PRECAMBRIAN
WINDERMERE
4 TOBY, HORSETHIEF CREEK
PURCELL (BELT)
UPPER
3 KITCHENER, SIYEH, WALLACE, DUTCH CREEK, MISSOULA, ETC.
LOWER
2 CRESTON, RAVALLI ETC.
1 ALDRIDGE, PRITCHARD
FAULT (defined, approximate, assumed)
117°
116°
115°
114°
113°
51°
50°
48°
47°

LEWIS SERIES

Distribution and Thickness

B. Willis (1902) defined and described the Lewis Series to include all the Late Precambrian rocks which are found just to the south of the International Boundary in Montana. The formations named in ascending order, were the Altyn, Appekunny, Grinnell, Siyeh, Sheppard and Kintla. The total thickness was given as 10,700 feet. His nomenclature was adopted by later authors who worked in nearby areas.

R.A. Daly (1912) used this terminology in his description of the rocks found mainly in the Clark range at the 49th parallel. His total thickness of the Precambrian rocks was 13,460 feet. He named the basal dolomite and argillite unit, the Waterton formation with type locality near Waterton Lakes, Alberta.

C.H. Clapp (1932) gave 50,000 feet for the thickness of the Precambrian sedimentary rocks equivalent to the Lewis Series near Missoula, Montana. He recognized the lower three formations of Willis, the Altyn, Appekunny and Grinnell, in his table of formations.

G.S. Hume (1933) reported 16,775 feet as the maximum thickness of the Lewis Series in the Waterton-Flathead map-area. He noted the tendency of the series to thin out towards the north. He gave a thickness of 1200 feet for the Waterton formation, but this is based on 200 feet of exposure and 1000 feet penetrated by a drill hole near Waterton Lakes, Alberta. Hume divided the Kintla formation into four divisions and noted that Daly observed only the lower members along the International Boundary.

C.L. Fenton and M.A. Fenton (1937) worked mainly in Glacier National Park, Montana. They recognized the stratigraphic units of Willis, but divided them into various members with a total thickness near 26,000 feet. They figured and described sedimentary structures and Precambrian algae which are recognized just below and above the Purcell lava.

C.O. Hage (1940) described and mapped the Lewis Series in the Beaver Mines area to the north of Waterton Lakes, Alberta. His total thickness of the series is given as 8,730 feet.

R.J.W. Douglas (1952) mapped in detail the Lewis Series exposed in the Waterton Lakes area, Alberta. His section is given in table 1, with a total thickness of 8,067 feet for the sedimentary rocks.

D.K. Norris (1959) mapped the geology of the Carbondale River map-area which is located immediately to the west of the Beaver Mines map-area. The total thickness of the sedimentary rocks is given as 8,910 feet as shown in table 1.

R.A. Price (1959) gave 6,640 feet as the maximum thickness of the Lewis Series in the Flathead map-area which is located immediately west of the Carbondale map-area.

C.P. Ross (1959) worked in Glacier National Park and the Flathead region, Montana. He gave 23,000 feet for the total thickness of the Lewis Series. His report on the geologic, structural and geomorphic studies of the late Precambrian rocks of northern Montana is probably the most comprehensive to date.

Table 1. Nomenclature and Thickness of Proterozoic Formations

	PURCELL MOUNTAINS			ROCKY MOUNTAINS		
	WESTERN PURCELLS (RICE)	DEWAR CREEK (REESOR)	CRANBROOK (RICE)	GALTON RANGE (SCHOFIELD)	CARBONDALE (NORRIS)	WATERTON (DOUGLAS)
Middle Cambrian	Milford Gp. Conformable(?) Lardeau Series 10,000'			Burton	Middle Cambrian	
Lower Cambrian	Badshot 100' Hamill Series 10,000'		Eager 6000' Disconformable Cranbrook 600'			
Windermere	Horsethief Ck. 5000' Irene Volc. 0-5000' Toby 250'-2000'		Unconformable	Disconformable	Unconformable	
Upper Purcell	Unconformable Mt. Nelson 3200' Dutch Creek 4300' Base not exposed	Top not exposed Dutch Ck. 1000' Purcell lava 200 Siyeh 2000' Kitchener 4700'	Gateway 2000' Purcell lava 450 Siyeh 2200' Kitchener 6000'	Roosville 600' Phillips 550' Gateway 1975' Purcell lava 400 Siyeh 4000' Wigwam 1200'	Kintla 1790' Sheppard 440' Purcell lava 295 Siyeh 1650' Grinnell 630' Appekunny 2100'	Top not exposed Kintla 1500' Sheppard 600' Purcell lava 200 Siyeh 3000' Grinnell 750' Appekunny 1100'
Lower Purcell		Creston 6500' Aldridge 15,500' Base not exposed	Creston 6300' Aldridge 16,000' Ft. Steele 7000' Base not exposed	MacDonald 2350' Hefty 775' Altyn 650' Base not exposed	Altyn 1300' Waterton 1500 Base not exposed	Altyn 500' Waterton 617' Base not exposed

Descriptions of Lewis Series Formations

The description of the Lewis Series is confined mainly to those formations found in the Waterton Lakes area. The section by Douglas (1952), which is given in Table 1, is used for the megascopic descriptions. The microscopic description is based mainly on the work of Daly (1912), Ross (1959) and a few thin sections of samples collected by the writer in Waterton and Glacier National Parks.

Waterton Formation--Douglas (1952) divided the Waterton formation into several units and stated, "The lowest beds outcropping on cliffs bordering Waterton Lakes between Cameron and Bertha Creeks, consist of 15 feet of grey weathering, banded and laminated, grey limestone, overlain by 35 feet of massive-bedded green and greenish grey dolomite, 37 feet of massive-bedded green argillite and 100 feet of buff weathering, cherty, grey dolomite with thin grey argillite bands. Higher strata are better exposed along Cameron Creek and in road cuts 2 to 3 miles above Cameron Falls. There, 105 feet of banded and streaked, grey limestone and dolomite interbedded with thin, grey argillite, and containing numerous algal growths in the lower part, are overlain by 95 feet of massive-bedded green and greenish-grey dolomite. The dolomite, in turn, grades upward into 130 feet of interbedded, banded and streaked, grey limestone and dolomite and fissile black argillite, and are succeeded by 100 feet of finely laminated and crossbedded, red, brown, and greenish grey dolomite with interbedded, thin grey and green argillite. The total thickness of the Waterton formation is 617 feet."

In thin section, the main constituents of the Waterton formation are carbonates which have an average diameter of 0.02 mm. Rhombohedral forms of dolomite are seen along with interlocked quartz and orthoclase grains. Minor accessories include hematite and magnetite. Carbon dust is present.

Altyn Formation--Douglas (1952) divided the Altyn formation into three parts and stated, "The lower part, 200 to 800 feet thick, comprises a basal section transitional to the underlying Waterton formation and occurring in thick beds partly mottled with red and brown spots, overlain by thinly bedded, finely laminated, grey dolomite, weathering light buff. The Middle and Upper parts are grouped together. The Middle Altyn is 200 to 400 feet thick and consists of thick, massive-bedded, cliff-forming sandy and gritty dolomite, chalky white-weathering algal dolomite and thin, fissile, black argillite. In the upper part, 150 to 200 feet thick, argillite is more abundant and is interbedded with sandy, gritty and laminated dolomite in beds 1 foot to 5 feet thick."

In thin section the lower part of the Altyn formation is composed of a fine-textured aggregate of closely packed anhedral, colourless carbonate (0.02 mm. diameter), quartz, feldspar, magnetite and carbon dust. The middle part is composed of coarser-grained constituents (0.3 mm. diameter), microperthite, orthoclase, quartz, chalcedony and oolite grains embedded in a carbonate base. The Upper part is composed of the following minerals with grain sizes ranging from 0.25 to 1.0 mm.; microperthite, microcline, orthoclase, rare plagioclase, oolite carbonate, chert and magnetite.

The average rock of the Altyn formation is composed of dolomite 75 per cent, quartz and chert 10 per cent, calcite 4 per cent and magnetite, kaolin, carbon dust, microperthite, orthoclase, microcline, plagioclase, and mica 10 per cent. No evidence of pronounced metamorphism of the sediment is noted.

Appekunny Formation:--G.S. Hume (1932, p. 5B) in the Waterton-Flathead area noted, "The contact between the Altyn and Appekunny formation is well defined, the top bed of the Altyn containing Cryptozoans in some abundance." According to Douglas (1952), the base of the Appekunny formation is marked by 20 to 75 feet of greenish-grey quartzite. This is overlain by massive green, and rare, red, argillite in which are two distinctive resistant beds. The remainder of the formation is dominatly green argillite, with thin, green quartzites and red argillite bands, which become more abundant near the top.

In thin section, the rocks of the Appekunny formation are composed dominantly of angular quartz grains intermixed with chlorite, sericite and iron oxides.

Grinnell Formation:--The Grinnell formation is composed of bright red and purplish argillite with thin green quartzite bands. White, green and red quartzites, and edgewise conglomerates are found in the upper half of the formation. The Grinnell argillite is characterized by uniform, even-bedded, thin rock units. Some stromatolites are recorded from the Grinnell argillite in Montana.

Daly (1912, p. 70) recorded a thin, basic amygdaloidal lava flow in his columnar section of the Grinnell formation. The Fentons (1937, p. 1888) noted that this flow is not exposed in sections south of the 49th Parallel.

In thin section the Grinnell argillites are composed of quartz and fine mica with some feldspar and minor carbonate. In the coarser rocks, the rounded quartz grains (average diameter 0.25 mm.) and alkali feldspars are scattered in a fine-grained argillaceous matrix. Some of the clastic grains are rimmed with overgrowths. Carbonate, argillaceous rock fragments and iron oxides are present in some cases.

Siyeh Formation:--Douglas (1952) in his description of the Siyeh formation in Waterton Lakes map-area stated, "The lower 500 feet contains much pale green argillite, with interbedded buff-weathering dolomite, finely laminated or sandy. Above these beds are 900 feet of mixed dolomites and limestone, in part exhibiting "molar-tooth" structures interbedded with some thin, black argillite. Algal limestones are common, one of which, about 50 to 100 feet thick, persists across the area. Thick green argillites occur in the upper 600 feet of the formation with three distinct bands of red argillite, the uppermost lying immediately beneath a dark, purplish-green basalt flow." This basalt flow is the Purcell lava, which will be discussed in the following chapter.

In the Carbondale River map-area, Norris (1959) divided the Siyeh formation into three parts. The lower part is composed of grey and green argillite, grey dolomite and limestone, grey algal limestone and dolomite, and oolitic limestone. The middle part is composed of grey, algal dolomite.

This variably dolomitized cryptozoan bed may be traced south through Waterton Park to Glacier National Park where it has been called the Conophyton zone (Ross, 1959, p. 37). In the Carbondale area the upper part of the Siyeh formation, which is found immediately below the Purcell lava, is composed of green, grey and red argillite, light grey, molar-tooth dolomite and algal limestone. The term "molar-tooth" was used by Daly (1912, p. 72-76) for structures in the Siyeh limestone which resembled the markings of an elephant's molar tooth.

In thin section, the main part of the Siyeh formation is composed of carbonate. Calcite cyrstals are embedded in a base of smaller sized carbonate. Minor quartz, feldspar, dust and pyrite grains are associated with the carbonate. In Glacier Park, sericite may be seen in thin sections of the Siyeh formation.

Sheppard Formation:--The Sheppard formation is composed of yellowish-weathering, siliceous, concretionary dolomite, quartzite and argillite. In Glacier National Park, the Sheppard is exposed coextensively with the Purcell lava from Granite Park northward to the International Boundary (Ross, 1959, p. 52). Here, some beds of conglomerate, which contain lava pebbles, are part of the Sheppard formation (Ross, 1959, p. 53). Daly (1912, p. 78) recorded a thin, local, basic and amygdaloidal lava in his section of the Sheppard formation.

In thin section, the main constituent of the Sheppard formation is dolomite (75 per cent), with an average grain size less than 0.1 mm. Some larger rhombohedral grains are enclosed in a fine-grained base of carbonate grains, quartz, sericite and minor feldspar.

<u>Kintla Formation</u>:--Willis (1902) named the youngest formation of the Lewis Series, the Kintla formation, which is composed of deep red, argillaceous quartzites and siliceous shales, with marked white quartzites and occasional calcareous beds. He noted the presence of casts of salt crystals as a significant constituent of this formation. Daly (1912, p. 82) recorded a 40 foot thick amygdaloidal lava in his columnar Section of the Kintla formation near the International Boundary. He noted, "Though this lava bed of the Kintla has been traced six miles to the westward, it is known to have formed but a single, local outflow of magma, lacking the singular persistence of the Purcell lava." Hume (1932, p. 6B) observed at least three porphyrite sills in the youngest beds of the Kintla formation in Waterton area.

From thin-section study, Daly (1912, p. 83) listed the minerals of the Kintla argillite as including clear quartz, fresh microcline and microperthite, cloudy orthoclase, little plagioclase embedded in an argillaceous cement. He recorded other minerals such as magnetite, apatite, sericite, kaolin, and minor carbonate.

GALTON SERIES

In the Galton Range, the Precambrian rocks are called the Galton Series (Daly, 1912, p. 97). This series is composed of eight formations and is about 11,500 feet thick, excluding the Purcell lava formation. Schofield's section is shown in Table 1. The formations are briefly described and correlated by Daly.

Description of the Formations of the Galton Series

Altyn Formation:--The Altyn formation is composed of thinly-bedded, siliceous dolomites and is easily traced west from the Lewis Range. The microscopic description of the Altyn dolomite of the Galton Range is similar to its equivalent in the Lewis Range.

Hefty Formation:--The Hefty formation is made up of massive-bedded, reddish sandstone and thin-bedded, red shale. Daly (1912, p. 100) considered the Hefty formation to be the equivalent of the lowermost Appekunny formation. In thin section the Hefty sandstone is composed of rounded quartz and feldspar grains (0.2 mm. in diameter), in a mixed cement of quartz, feldspar, carbonate and iron oxides.

MacDonald Formation:--The MacDonald formation is dominantly green argillite, with some red argillite and quartzite. The upper and lower parts weather buff, the middle part grey.

In thin section the MacDonald argillite is composed mainly of argillaceous material, with quartz, feldspar, sericite, chlorite and minor carbonate grains.

Wigwam Formation:--The Wigwam formation consists mainly of red or brownish-red sandstones with red argillite partings. The fine-grained sandstone is composed of quartz, K-feldspar, plagioclase, chert, kaolin, sericite and iron-rich cement. Daly (p. 104) correlated the Wigwam with Grinnell formation of the Lewis Series.

Siyeh Formation:--The Siyeh formation is composed of massive limestone, dolomite, and argillite. These beds were considered by Daly to be identical to those overlying the Grinnell formation in the Lewis Range. The Siyeh is overlain by the Purcell lava formation, described in the next chapter.

Gateway Formation:--The Gateway formation is composed of two main rock units. The basal dolomite and argillite unit is similar to the Sheppard formation. The upper unit is characterized by green argillite and quartzite, with abundant casts of salt crystals up to 2 cm. in diameter. Daly (1912, p. 108) correlated the thick, upper rock unit of the Gateway to the Kintla formation. He noted that neither in the Gateway nor in the overlying Phillips formations were there any lava flows.

In thin section, the basal Gateway is made up mainly of K-feldspar, quartz and plagioclase grains. Sericite, chlorite, secondary quartz and minor zircon and tourmaline were observed in a few thin sections from Phillips Creek (see Chapter III).

Phillips Formation:--The Phillips formation is composed of thin-bedded, purplish or brownish argillite and sandstone. In thin section these rocks are made up of quartz, K-feldspar, plagioclase, and chert, embedded in a base of sericite, magnetite and hematite. Daly correlated the Phillips formation with the upper part of the Kintla formation.

Roosville Formation:--The Roosville formation is composed of green, thin-bedded argillite with interbedded quartzite. The argillite is made up of angular quartz and feldspar in a matrix of sericite, chlorite, iron oxides and argillaceous material.

PURCELL SYSTEM

Precambrian sedimentary rocks in the Purcell Mountains near the International Boundary were described and named the Purcell Series by Daly (1912).

S.J. Schofield (1915, p. 25) redefined this series to include six formations with a total thickness of 23,800 feet. In ascending order, these are the Aldridge, Creston, Kitchener, Siyeh, Purcell lava and Gateway formation.

J.F. Walker (1926, p. 7) in the Windermere area, proposed a division between the Lower and Upper Purcell which he placed at the top of the uppermost flow of the Purcell lava. His Upper Purcell series was composed of the Dutch Creek formation (Gateway, Phillips and Roosville equivalents) and the overlying Mt. Nelson formation.

H.M.A. Rice (1937, p. 4) gave 37,000 feet for the thickness of the Purcell series in the Cranbrook map-area, and later (1941, p. 7) reported 45,000 feet for the thickness of the series in the Nelson map-area. His series of rocks included the formations which were introduced by Schofield, plus the Fort Steele formation. The Fort Steele formation underlies the Aldridge formation, and is only recognized in the western Rocky Mountains.

J.E. Reesor (1957b) in the Lardeau map-area re-defined the Lower and Upper Purcell system on a lithological basis, with the Upper Purcell composed of rocks more calcareous than the Lower Purcell. He stated, "No volcanic flows are found in the Siyeh formation north of latitude 50 degrees or west of 116 degrees longitude in this region. Thus the Lower and Upper Purcell are here re-defined so that the Lower Purcell (Aldridge and Creston formations) consists of about 20,000 feet of very fine-grained quartzites and argillaceous quartzites with associated argillites and slates, and the Upper Purcell (Kitchener, Siyeh, Dutch Creek and Mt. Nelson formations) consists of about 12,000 feet of variously coloured argillites and quartzites and their limy and dolomitic equivalents as well as some limestone and dolomite."

Description and Correlation of the Rocks in the Purcell System

The descriptions and correlations of the rocks in the Purcell System are taken largely from publications of the Geological Survey of Canada. Some of the microscopic descriptions are supplemented from thin-section data observed by the writer.

Fort Steele Formation:--The Fort Steele formation is about 7000 feet thick, with the base not exposed in the Cranbrook area (Rice, 1937, p. 4). It is composed of four mappable rock units; white quartzite, striped argillite, black dolomitic argillite and green dolomitic argillite.

The lowest unit is more than 1000 feet of white quartzite and argillaceous quartzite with well preserved cross-bedding. The main

constituent is quartz (up to 5.0 mm. in diameter) in a matrix of white mica, green biotite with minor K-feldspar, zircon, apatite, sphene, calcite and chlorite.

The white quartzite unit grades upward to 2000 to 3000 feet of laminated dark grey argillite and white to grey quartzite. The grey quartzite consists of fine, sutured, quartz grains in a matrix of white mica. Other minerals present are biotite, tourmaline, and minor amounts of microcline, plagioclase, zircon, apatite, clay minerals and magnetite.

The argillite unit is overlain by 2000 to 3000 feet of massive, black, calcareous or dolomitic argillite. This rock is composed mostly of calcite, in an argillaceous matrix with quartz, mica and graphite.

The uppermost unit, 300 to 500 feet thick, consists of very massive, grey-green, dolomitic argillite. The main constituents are dolomite, white mica, quartz and minor amounts of sphene, tourmaline, K-feldspar, apatite, zircon and pyrite.

The Fort Steele formation has been mapped east of the Rocky Mountain Trench but may have equivalent rocks in the Purcell Mountains. G.B. Leech (1958b) stated, "The Aldridge of the Rockies is thinner than was previously believed and is probably equivalent to only the upper part of that in the Purcells and the Fort Steele formation beneath it may be partly or entirely equivalent to Aldridge rocks in the Purcell Mountains."

<u>Aldridge Formation</u>:--The Aldridge formation consists of about 16,000 feet of rusty-weathering, very fine-grained, argillaceous quartzites and argillites in the Cranbrook area (Rice, 1937, p. 6). Primary sedimentary

structures such as cross-bedding, mud-cracks and ripple marks are abundant. The argillaceous quartzites consist mainly of fine, angular quartz grains and small flakes or aggregates of brown biotite. Plagioclase and calcite may be present. Clay minerals, garnet, tourmaline, zircon, sphene, magnetite, pyrite, white mica, chlorite and apatite occur in small amounts. The argillites are smooth, dense and have a smaller content of quartz than the quartzites.

The Aldridge formation is divided into a lower division, about 4500 feet thick and an Upper division, about 11,000 feet thick in the Dewar Creek map-area (Reesor, 1958).

The Lower division is mainly rusty-weathering, light-coloured, very fine-grained, thin-bedded quartzite, sericitic siltstone and argillaceous quartzite. There is nearly 1000 feet of Moyie metadiorite sills in this division.

In thin section, the Lower division contains fine-grained recrystallized quartz about 0.05 mm. in size. Shreds and flakes of brown biotite occur abundantly and are both detrital and metamorphic in origin. Fine-grained, fibrous, sericite (recrystallized argillaceous material) may form up to 30 per cent of the thin section. Porphyroblastic muscovite and chloritoid may be seen. Accessories are magnetite, hematite, zircon, apatite and tourmaline.

The Upper Aldridge division is a uniform sequence of thin-bedded quartzites, with interbedded argillite and argillaceous quartzite. Near the top of this division, there is a gradational change to rusty-weathering, thin-bedded, platy, black and white laminated argillites.

In thin section, the quartzites of the Upper division have two principal grain sizes of detrital material. Angular quartz grains (0.3 to 0.5 mm.) are embedded in interstitial quartz and sericite grains of less than 0.03 mm. in size. Rare feldspar and biotite are present along with accessories such as chlorite, zircon, magnetite, hematite and tourmaline. The argillites contain small quartz grains (0.1 mm.) in a fine mesh of sericite. Biotite porphyroblasts occur in patches and accessories include magnetite, zircon, apatite, hematite and tourmaline.

In the Upper Aldridge division of the Dewar Creek area, primary structures such as mud-cracks, ripple marks and cross-bedding are rare or absent but graded bedding is very common. Reesor (1958, p. 11) considered these rocks to be characteristic of the greywacke suite.

The Aldridge formation is mainly argillite in the Rocky Mountains but changes to predominantly quartzitic rocks west of the Trench (Rice, 1937, p. 7). The Prichard formation (Aldridge equivalent) of Idaho and Montana undergoes a similar lithologic change, from quartzitic rocks in the west to predominantly argillites in the east. In the Belt Mountains, the Prichard does not occur and the underlying Neihart quartzite overlies the Archean (Clapp and Deiss, 1931, p. 694). Between the Purcell and Galton series, Schofield (1915, p. 50) shows no correlative of the Aldridge formation in the Galton range. The oldest formation exposed in the Galtons is apparently much younger than the Aldridge.

The writer studied the Neihart quartzite in the Belt Mountains of Montana and it appears that the Neihart and Fort Steele formations are lithologically and mineralogically similar rock units.

Creston Formation:--The Creston formation in the Cranbrook area is about 6300 feet thick and consists of green or grey-weathering, impure, fine-grained quartzites and argillites. Purple and white argillaceous quartzites are common and a light-coloured quartzite with fine purple lines is diagnostic of this formation (Rice, 1937, p. 8). Ripple marks, mud-cracks and rain prints are present.

In thin sections of the Creston formation, strained quartz grains with overgrowths are most abundant, and occur with feldspar and white mica. Magnetite, pyrite, chlorite, hematite and minor amounts of carbonates, tourmaline and biotite are present.

In the Dewar Creek area, the Creston formation consists of dark-weathering, black and grey argillites at the base of the formation, and grey, green, purple and white argillaceous quartzites in the upper part of the formation (Reesor, 1958, pp. 14-17). It varies in thickness from 6000 to 6500 feet and appears to thin to the west to about 4100 feet. Primary sedimentary structures are present.

In thin section, the rocks of the Creston formation consist of quartz (0.05 mm. in size) with various amounts of sericite and chlorite. Biotite porphyroblasts are common and feldspars are rare. Zircon, hematite, magnetite, and chloritoid are present in varying amounts.

Near the Rocky Mountain Trench, the upper part of the Creston contains some of the coarsest clastic rocks in the Purcell System (Reesor, 1957a, p. 155). This same rock unit becomes more calcareous and argillaceous to the east.

Kitchener Formation:--The Kitchener formation is about 6000 feet thick in the Cranbrook area (Rice, 1937, p. 11) and is composed of buff-weathering, variously coloured, thin-bedded, calcareous and dolomitic argillite. Mud-cracks and ripple marks are present.

In thin-sections of the Kitchener, calcite and dolomite may make up to 95 per cent of the rock. White mica and argillaceous material are abundant. Quartz, feldspar, apatite, tourmaline, zircon, magnetite and pyrite are present.

In the Dewar Creek area, the Kitchener formation is about 4700 feet thick and consists of the following rock types: very fine-grained, reddish-weathering quartzite and siltstone; fine, buff-weathering, cream-coloured, sandy dolomite; black limestone; and thin-bedded argillite (Reesor, 1958, pp. 17-20). Primary features are common.

Thin sections of the Kitchener show fine quartz (up to 0.05 mm. in size), argillaceous material and grains of carbonate. Accessory tourmaline, pyrite, hematite and rare zircon are present.

Schofield (1915, pp. 50-52) correlated the Kitchener formation with the Altyn, Hefty, MacDonald and Wigwam formations of the Galton Series. Although Reesor (1957a, p. 154) noted this correlation of Schofield's, he did not include the Altyn formation as equivalent to part of the Kitchener formation.

Siyeh Formation:--The Siyeh formation is about 2200 feet thick in the Cranbrook area and consists of variously coloured, thin-bedded argillite and argillaceous quartzite. Primary structures are common. The Purcell lava formation occurs at the top of the Siyeh formation.

In thin sections of the Siyeh, small angular quartz grains are found in a matrix of white mica and argillaceous material. Feldspar, hematite and tourmaline are present.

In the Cranbrook area, Rice (1937, p. 11) noted the difficulty of identifying and correlating the Siyeh formation. Leech (1960) attempted to clarify the situation and stated, "The stratigraphic equivalent of the base of the Siyeh in the Rockies has not yet been recognized in the Purcell Mountains. The succession formerly called Siyeh in the Purcells includes, on one hand, the equivalent of merely the upper part of the true Siyeh, and on the other, in some localities, the probable equivalent of the base of the Gateway formation of the Rockies. The inclusion of the latter arises from differences in the occurrence of the Precambrian lavas whose top has been taken to mark the base of the Gateway. In the Galton Range of the Rockies, the lavas occur in a single zone with only small intercalations of sediments, whereas in the Purcells south of 49° 30' the lavas occur through a greater stratigraphic range and the highest flows are separated from the lower main lavas by considerable thicknesses of sediment. The lavas of the Galton Range correspond to the lower, main lava zone in the Purcells near the International Boundary".

In the Dewar Creek area the Siyeh formation is up to 2000 feet thick (Reesor, 1958) and consists of very thin-bedded, green, purple and grey argillites, slates and argillaceous quartzites. These rocks are similar in thin section and contain identical primary structures with those found in the underlying Kitchener formation. At the top of the Siyeh formation, a sheared band of igneous breccia and tuff occurs locally at a stratigraphic position equivalent to the Purcell lava horizon in the Cranbrook area.

<u>Gateway Formation</u>:--The Gateway formation in Cranbrook area consists of about 2000 feet of variously coloured argillaceous quartzites, dolomitic quartzites and dolomites. The most diagnostic feature of this formation is an abundance of well-formed salt casts (Leech, 1959a). Ripple marks, cross-bedding, oolitic and pisolitic beds and concretionary or layered algaloid structures are present.

In thin-sections of the Gateway, Rice (1937, p. 12) noted that quartz is always present and may be up to 5.0 mm. in diameter. Dolomite is the most common constituent of these rocks. The argillaceous quartzites contain quartz in white mica, and locally a considerable amount of feldspar. Hematitic argillaceous material, chlorite, zircon, biotite, apatite, pyrite and magnetite have been recognized in the Gateway formation.

There are at least two exposures of Gateway formation in the Purcell Mountains where the basal rock unit is composed of basaltic pebbles.

In the Kootenay River valley, Schofield (1915, p. 36) recorded, "The base of the Gateway rests on the Purcell lava conformably and is formed of a fine-grained grit containing pebbles of the Purcell lava as well as a few pebbles of quartzite."

Towards the west, near Yahk Mountain, Schofield (1915, p. 78) noted, "The upper surface of the lava is irregular, showing flow structure. Resting on this surface is a conglomerate composed of rounded fragments of fine-grained basalt in a sandy cement. The fine conglomerate also consists of volcanic material in an argillaceous cement."

Dutch Creek Formation:--The name Dutch Creek was applied to rocks equivalent to the Gateway, Phillips and Roosville formations found near and north of latitude 50 degrees by Walker (1926).

In the Dewar Creek area, the Dutch Creek formation is about 1000 feet thick, but is poorly exposed (Reesor, 1958, p. 21). It is similar in lithology to the underlying Siyeh and Kitchener formations, and is composed of fine-grained quartzite, argillite and dolomite. Mud-cracks and cross-bedding are common.

Immediately to the east of Dewar Creek, Leech (1960) subdivided the Dutch Creek formation into the Gateway, Phillips and Roosville formations. He stated, "The red, mica-flecked Phillips formation is distinctive. Its occurrence in the Purcells, shown here for the first time, provides a valuable new correlation across the Rocky Mountain Trench. The recognition of Phillips formation at Skookumchuck Creek permits a closer comparison of the Dutch Creek strata of the northwest with the equivalent Gateway, Phillips and Roosville sequence of the south and east."

In the Western Purcell Mountains, the Dutch Creek formation is about 4300 feet thick and is composed mainly of slaty argillites (Rice, 1941, p. 11). Dolomite, argillaceous limestone and quartzite occur throughout the formation.

Mount Nelson Formation:--In the Nelson map-area, the Mount Nelson formation is about 3200 feet thick (Rice, 1941, p. 12). It is lithologically similar to the underlying Dutch Creek formation, but has more and thicker beds of dolomite. A thick band of light-coloured, quartzite at the base locally makes a good horizon marker.

The Mount Nelson formation is absent in the Rocky Mountains (Leech, 1960).

WINDERMERE SYSTEM

Originally defined by Walker (1926), the Windermere comprises the Toby Conglomerate, Irene Volcanics and the Horsethief Creek formation, lying unconformably on the Upper Purcell strata.

Description and Correlation of the Rocks in the Windermere System

Toby Conglomerate:--In the Windermere or type section area the Toby shows marked lateral variation in thickness and degree of composition. Slate, shale, limestone or quartzite phenoclasts, with an average size from 4 to 10 inches, are found scattered in a slaty matrix.

J.F. Walker (1926, p. 15) stated, "The size and shape of the boulders, the character of the formation as a whole, and the evident derivation of the boulders from the immediately underlying Purcell series indicate that the materials were not transported any great distance. The marked variation in thickness of the conglomerate from 50 to 2000 feet is strongly suggestive a fan structure and the rock may well be called a fanglomerate."

In the Nelson map-area the Toby formation (250 feet to 2000 feet thick) varies from a breccia to a conglomerate, with phenoclasts up to boulder size, predominantly composed of quartz, feldspar, quartzite or dolomite (Rice, 1941, pp. 14-15). The matrix may be siliceous argillite,

limestone or argillite and the ratio of phenoclasts to matrix is quite variable.

The Toby conglomerate, or its equivalents may be traced from the Bow River of the Rocky Mountains, southwest through the Purcell Mountains and into northeastern Washington over a distance of about 200 miles (Reesor, 1957a, p. 151). The equivalents of the Toby formation are called the Irene Conglomerate near the International Boundary (Daly, 1912) and the Shedroof conglomerate in northeastern Washington (Park and Cannon, 1943).

<u>Irene Volcanic Formation</u>:--The Irene volcanic formation occurs only in the vicinity of the International Boundary (see Figure 3).

Daly (1912, pp. 145-147) gave the first detailed description of this formation and stated, "The great bulk of the formation is composed of a notably uniform type of highly altered andesitic lava, now typical greenstone. It is a dark green or greenish grey, compact, schistose rock, in which, as a rule, there is scarcely a trace of the minerals originally crystallized out of the magma. A large proportion of the greenstone is amygdaloidal, the amygdules (composed of calcite or, much more rarely, of quartz) being mashed out into thin lenses parallel to the pronounced schistosity. While the greenstone has been essentially derived from surface lava flows, it is usually impossible to distinguish the limits of any one flow. The difficulty of doing this is evidently due in part to the intense mashing and metamorphism of the lavas. It appears probable that, while the great mass was accumulated by many successive flows, each flow was of considerable thickness."

On the basis of microscopic study, Daly listed the following minerals in the volcanics: uralite, chlorite, epidote, quartz, calcite, limonite, sericite, saussurite, biotite, pyrite, magnetite, leucoxene, ilmenite and labradorite.

Rice (1941, pp. 15-17) described the Irene formation southwest of Kootenay Lake, and called it a, ".... fine-grained, sheared greenstone or hornblende schist." Conglomerate and limestone is found interbedded with the volcanics. There are both intrusive and extrusive phases of this greenstone. Rice noted that the greenstone is composed essentially of actinolite, quartz, and andesine with minor amounts of leucoxene, apatite, zircon, chalcopyrite, pyrite and epidote.

The Irene volcanic formation thins and finally disappears just to the north of the 49th parallel. However, these volcanics are correlated with the Leola volcanics of northwestern Washington where they are reported to be up to 9000 feet thick (Park and Cannon, 1943, p. 9).

Horsethief Creek Series:--The Horsethief Creek Series is about 5000 feet thick in the Nelson map-area, and is made up chiefly of slate, quartzite, conglomerate and limestone (Rice, 1941, pp. 17-19). These rocks are the youngest Precambrian strata in the thesis area and may be correlated with the Hector and Corral Creek formations, and the Miette formations of the Rocky Mountains (Reesor, 1957a, p. 160).

SUMMARY AND CONCLUSIONS

A summary of the Precambrian stratigraphic events in the thesis area may be as follows:

(1) Deposition of a thick and conformable succession of very fine-grained clastic rocks in a shallow sea, in the area now occupied by the Rockies, Purcells and the area to the west and north of these mountains. These rocks are now represented from east to west by the Lewis Series (11,000 feet thick), Galton Series (13,000 feet thick) and the Purcell System (45,000 feet thick). The base of the Lewis Series is the Lewis fault plane. The basal beds of the Galton Series and the Purcell Series are not exposed. Shallow water features, including mud-cracks, ripple marks and cross-bedding are common throughout the succession, except for about 11,000 feet of Upper Aldridge formation in the Dewar Creek area. Since the thickest accumulation of sediments are found in the west and no eastern equivalents of Aldridge are known, sedimentation may have begun in the west and extended eastward (Reesor, 1957a, p. 157). The basal Fort Steele formation which is similar in habit to a "lag" deposit (beach-type) may mark the ancient shoreline in early Purcell time. There is no direct evidence to indicate a western or northern source area for these sediments. The basement rocks in Alberta and the Archean crystalline rocks in the Belt Mountains of Montana may have been the source areas (Warren, 1951; Reesor, 1957). The Lewis Series thins out to the north. The total depositional thickness of sedimentary formations above the crystalline basement is not known for the Lewis, Galton and Purcell series. Deep drilling in southwestern Alberta has not encountered sedimentary rocks similar to the Lewis Series.

(2) Basaltic vulcanism during the Siyeh epoch in the Rocky-Purcell mountain terrain. In the Lewis Series, there are a number of thin, local flows above and below the main volcanic horizon. Pillow structures in the lava are well preserved. Thin, basic intrusive rocks are found in all formations except the two basal rock units, the Waterton and Altyn formations.

In the West, there are at least two major periods of basaltic flow separated by hundreds of feet of Siyeh strata. Thick, basic intrusive rocks are most common and abundant in the Aldridge formation. Some similar intrusions are found in younger formations but they are thinner and fewer in number.

(3) Sedimentation continued without marked interuption during the subaqueous vulcanism throughout the region. Abundant salt casts suggest a more arid climate. Red beds and algae-bearing rocks are common. Coarse-grained rocks of the Gateway and Sheppard formations with pebbles of Purcell lava, may indicate the beginning of a major uplift in the area.

(4) Deformation of the entire succession of rocks, with a more pronounced degree of metamorphism in the west. In the St. Mary Lake area, Precambrian granites are known to occur (Leech, 1961). The intensity of this deformation (East Kootenay Orogeny, White, 1959) is marked by open folds over most of the area. Walker (1926) reported an angular unconformity of 45 degrees between the Purcell and Windermere Systems in the Windermere area.

(5) Deposition of the Windermere System to the northwest of a boundary marked by the Purcell divide, extending northward into the Rocky Mountains. Large angular and rounded boulders of the underlying Purcell formations and some that were derived from a granitic and gneissic terrain, are found in the Toby Conglomerate. This conglomerate is seen to lie on different horizons of the Purcell. The highly metamorphosed Irene Volcanic formation, which is interbedded with limestone and conglomerate, is found above the unconformity and therefore considerably younger than the Purcell lava.

CHAPTER III - EXTRUSIVE PHASE

INTRODUCTION

Exposed in the Proterozoic rocks of the Rocky-Purcell Mountain terrain from Logan Pass, Montana (latitude 48° 45') northward to Lussier River, British Columbia (latitude 50°) is a widespread lava formation called the Purcell lava. The known areal extent of this formation is shown in Figure 3. The distribution of outcrops suggests there may be two main areas of Purcell lava which are centered near the Kootenay River in the west and the Flathead River in the east. The outcrop pattern is due in part to lack of mapping, cover and erosion of the lava. The eastern Purcell lava thickens northward from zero feet near Logan Pass, Montana to about 300 feet near latitude 49° 30'. The western Purcell lava formation is absent near latitude 50°, British Columbia and is about 500 feet near the International Boundary. There are no known exposures of Purcell lava in the central portion of the Rockies from the Galton Range east to the Flathead River.

The Purcell lava formation consists of a number of highly altered amygdaloidal and porphyritic basaltic flows, tuffs and agglomerates which are found interbedded with sediments in the Lewis, Galton and Purcell series. Elliptical structures, composed of pillow lava and "balled-up" sedimentary material are often found near the base of the formation. The flows are now composed principally of altered plagioclase phenocrysts, aligned in a groundmass of feldspar, chlorite and iron oxides. The chlorite is believed to have replaced olivine, pyroxene, plagioclase and much of the groundmass, which was probably originally a glass.

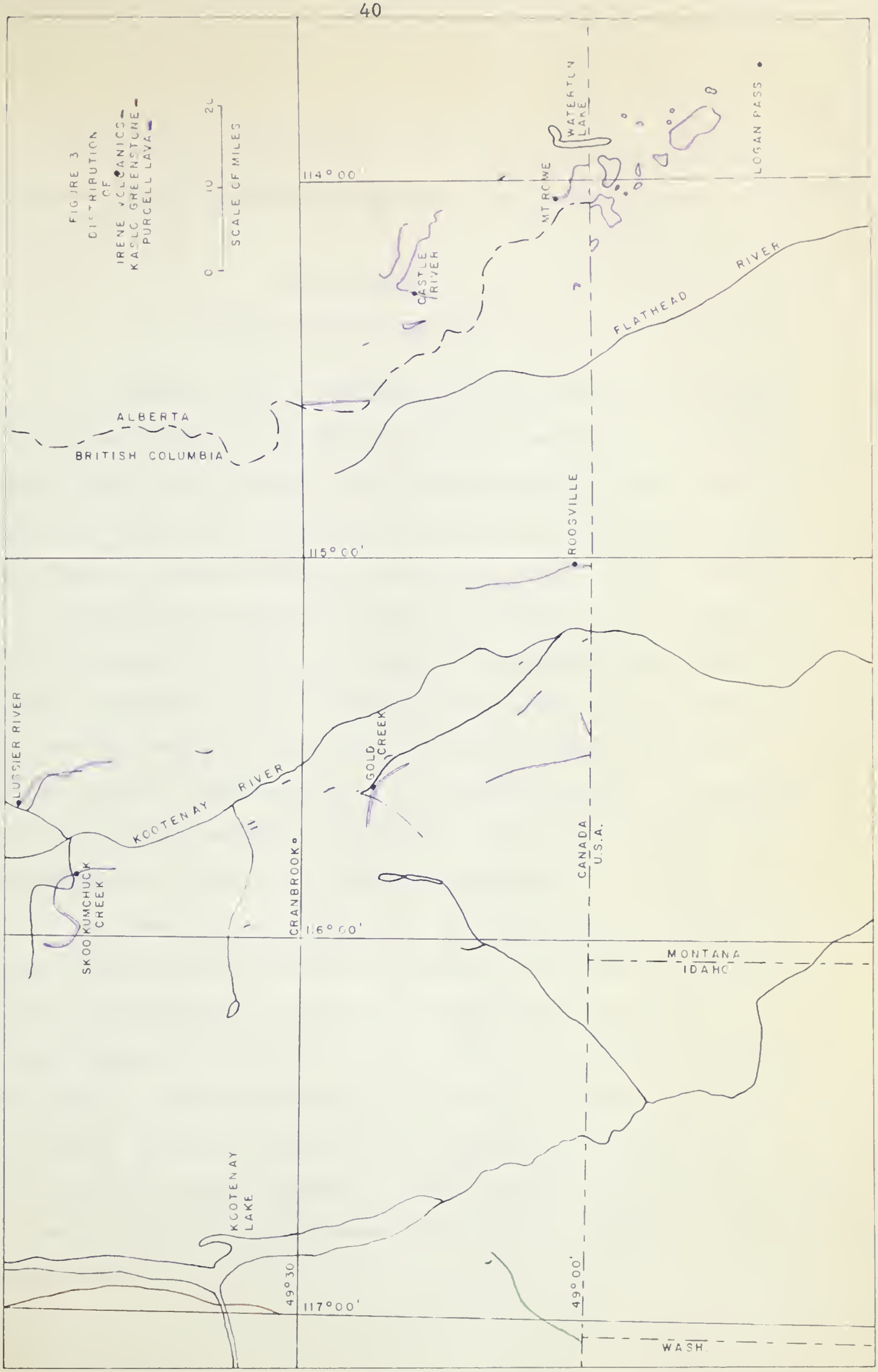


FIGURE 3
DISTRIBUTION
OF
IRENE VOLCANICS
KASLO GREENSTONE
PURCELL LAVA
0 10 20
SCALE OF MILES
WATERTON LAKE
LOGAN PASS
MT ROWE
114° 00'
CASTLE RIVER
FLATHEAD RIVER
ALBERTA
BRITISH COLUMBIA
ROOSVILLE
115° 00'
LUSSIER RIVER
KOOTENAY RIVER
GOLD CREEK
SKOOKUMCHUCK CREEK
CRANBROOK
CANADA
U.S.A.
116° 00'
MONTANA
IDAHO
KOOTENAY LAKE
49° 30
117° 00'
49° 00'
WASH.

Thin, local, pyroxene-bearing diabase flows occur in the Lewis series but none are reported in the Galton or the Purcell series.

LEWIS SERIES

Glacier National Park Area

G.I. Finlay, (1902) was probably the first observer to fully describe the basic igneous rocks which are found in the Waterton and Glacier National Parks area. He noted a fine-grained diabase, 42 feet thick, exposed on Grinnell and Sheppard Mountains near Swiftcurrent Pass, Montana (see Figure 4). He described this flow-rock and stated (1902, p. 349), ".... the extrusive character of the flow is well shown, for its upper surface is ropy and vesicular, with amygdaloidal cavities containing calcite." The main constituents of this diabase, as given by Finlay, were red-brown augite and long slender plagioclase laths exhibiting a diabasic texture. Chlorite is found in considerable amount, an alteration product of olivine, augite and plagioclase. Other minerals listed were secondary calcite, apatite and titaniferous magnetite.

R.A. Daly (1912, p. 217) studied the same diabase as noted by Finlay, exposed near Swiftcurrent Pass, Montana. He recorded that the Purcell lava formation is composed of two flows which underlie the Sheppard formation and overlie the Siyeh argillites. The lower flow, (40 feet thick) is characterized by pillow structures. The upper flow (18 feet thick is composed of normal Purcell amygdaloid. The pillows are round, spheroidal-shaped and range in size from about one to three feet in diameter. They are mostly composed of vesicular, microporphyritic and diabasic basalt.

FIGURE 4

GEOLOGIC SKETCH MAP
LOGAN PASS AREA, MONT.
AFTER C P ROSS (1959)

0 MILES 2

MG	DIABASE
MI	MISSOULA GP
SH	SHEPPARD
PU	PURCELL LAVA
SI	SIYEH
GR	GRINNELL
AP	APPEKUNNY
AL	ALTYN

GEOLOGIC CONTACT _ _
SAMPLE LOCATION •

L.D. Burling (1916, p. 235) described the ellipsoidal Purcell lava on Sheppard Mountain, Glacier National Park (Figure 4). The lava (150 feet thick) occurs in flat-lying, green, Siyeh argillites and is composed of six or more successive flows, separated in part by sediments. Dense, homogeneous spheroidal masses about 2 feet in diameter are found in the lower 30 feet of the flow. They are separated by chert or drusy cavities. The bottom of the flow is very irregular and accumulations of mud are incorporated in the flow. The individual spheroids are united towards the top of the flow and have formed an uneven upper surface. The upper 20 feet of the entire flow is massive but very porous. Vesicles are common in the basal portions of several of the individual flows. Burling also described the Swiftcurrent Pass lavas and concluded that they were subaqueous in origin.

Fenton and Fenton (1937, p. 1898) noted that the most southerly exposure of the Purcell lava is found about 0.8 mile south of Swiftcurrent Pass.

C.P. Ross (1959, pp. 51-52) mapped the Purcell lava in Glacier Park and emphasized that all the lava appeared to be too altered for precise determination. He described in detail the lava exposed at the south end of Flattop Mountain near Swiftcurrent Pass (see Figure 4 for location) and stated, "Traces of diabasic texture remain, and there are remnants of phenocrysts that may have originally been augite and olivine. Some of the rock contains feathery plagioclase laths with the habit of a calcic plagioclase but with indices of refraction close to that of Canada Balsam. These are crowded with specks of a secondary mineral of high index and low birefringence, presumably a chlorite. The main part of the laths now

approximate oligoclase or albite-oligoclase in composition but may well have resulted by recrystallization from an originally more calcic plagioclase. Much of the rock consists of a fine-grained nearly opaque aggregate of secondary minerals that include chlorite, sulfides, calcite, quartz and possibly serpentine."

Waterton National Park Area

In the Clark Range, Daly (1912, p. 213) traced the Purcell Lava (260 feet thick) along the International Boundary for 25 miles and noted its prominent position between the Siyeh and Sheppard formations of the Lewis series. He described the whole lava formation as a homogeneous, dark, greenish-grey to blackish amygdaloid, scoriaceous and of typical ropy structure at the upper contact. Calcite and quartz amygdules are abundant and may be up to 8 inches in length. He found one local variation of the lava where it exhibited, "rolled-in lava-crust forms". The lava was all highly altered, but he recognized the following minerals: labradorite (An_{50}), chlorite, calcite, kaolin, limonite, magnetite and apatite.

Daly described local lava flows in the Grinnell, Sheppard and Kintla formations, which are found east of the Flathead valley and north of the 49th Parallel.

A dark, green-grey, altered, amygdaloidal lava (20 feet thick) is found in the Grinnell formation, about 355 feet below the base of the Siyeh formation. In thin section the lava is composed of labradorite microphenocrysts in a matrix of chlorite, quartz, calcite and leucoxene. The amygdules are filled with chlorite.

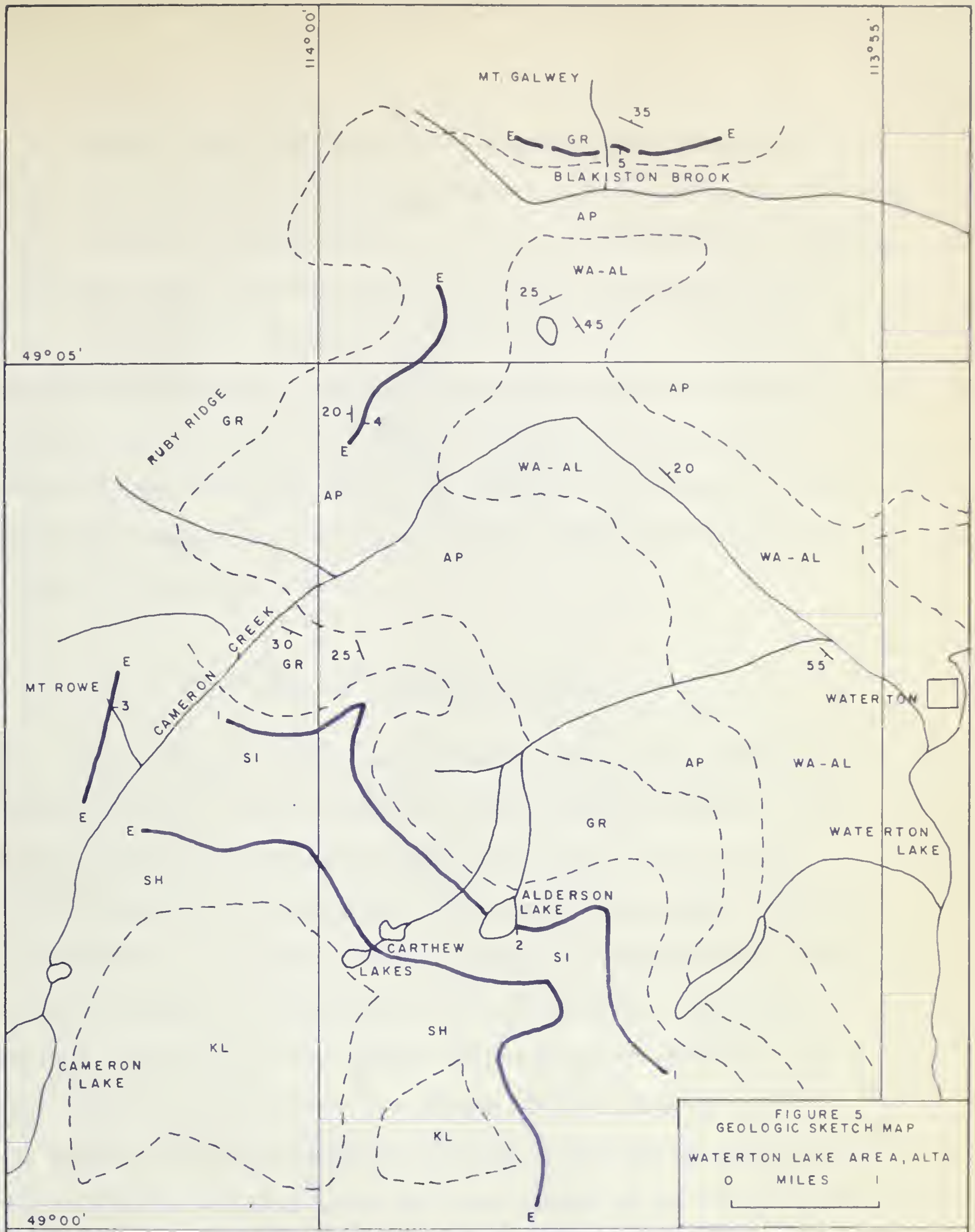


FIGURE 5
GEOLOGIC SKETCH MAP
WATERTON LAKE AREA, ALTA
0 MILES 1

LEGEND

LEWIS SERIES

I INTRUSIVE
KL KINTLA
SH SHEPPARD
E EXTRUSIVE
SI SIYEH
GR GRINNELL
AP APPEKUNNY
AL ALTYN
WA WATERTON

REFERENCES

R J W. DOUGLAS
G S C. MAP 52-10

G.S. HUME (1932)
G S C SUMM RPT. B

LOCATION OF SAMPLES

5 BLAKISTON BROOK
4 RUBY RIDGE
3 MT ROWE
2 ALDERSON LAKE

BEDDING
GEOLOGIC CONTACT ---

Another highly vesicular and amygdaloidal lava, 35 feet thick, is found near the base of the Sheppard formation. This lava contains vesicles which are mostly filled with calcite, less often with granular or radially crystallized quartz and some are filled with both calcite and quartz.

A 40 foot flow of basic vesicular lava occurs in the Kintla formation about 6 miles to the northwest of the lava in the Sheppard formation. Daly (1912, p. 82) stated, "Though this lava bed of the Kintla has been traced six miles to the westward, it is known to have formed but a single, local outflow of magma, lacking the singular persistence of the Purcell lava".

Ruby Ridge and Blakiston Brook Area

R.J.W. Douglas (1952) mapped diabase sills in the Appekunny formation and the Grinnell formation on Ruby Ridge and Blakiston Brook respectively at Waterton National Park (see Figure 5 for location). Recent studies by the writer suggest that these basic igneous rocks are diabase flows. In the field the upper contacts of these igneous rocks are poorly exposed, but the upper surface is irregular, amygdaloidal and shows no sign of a baked igneous contact with the sediments. The lower contacts of the diabase flows (about 50 feet thick) are always well exposed, sharp and regular in outline. A well-marked hornfels is developed in the sediments below the lower contact of the flows.

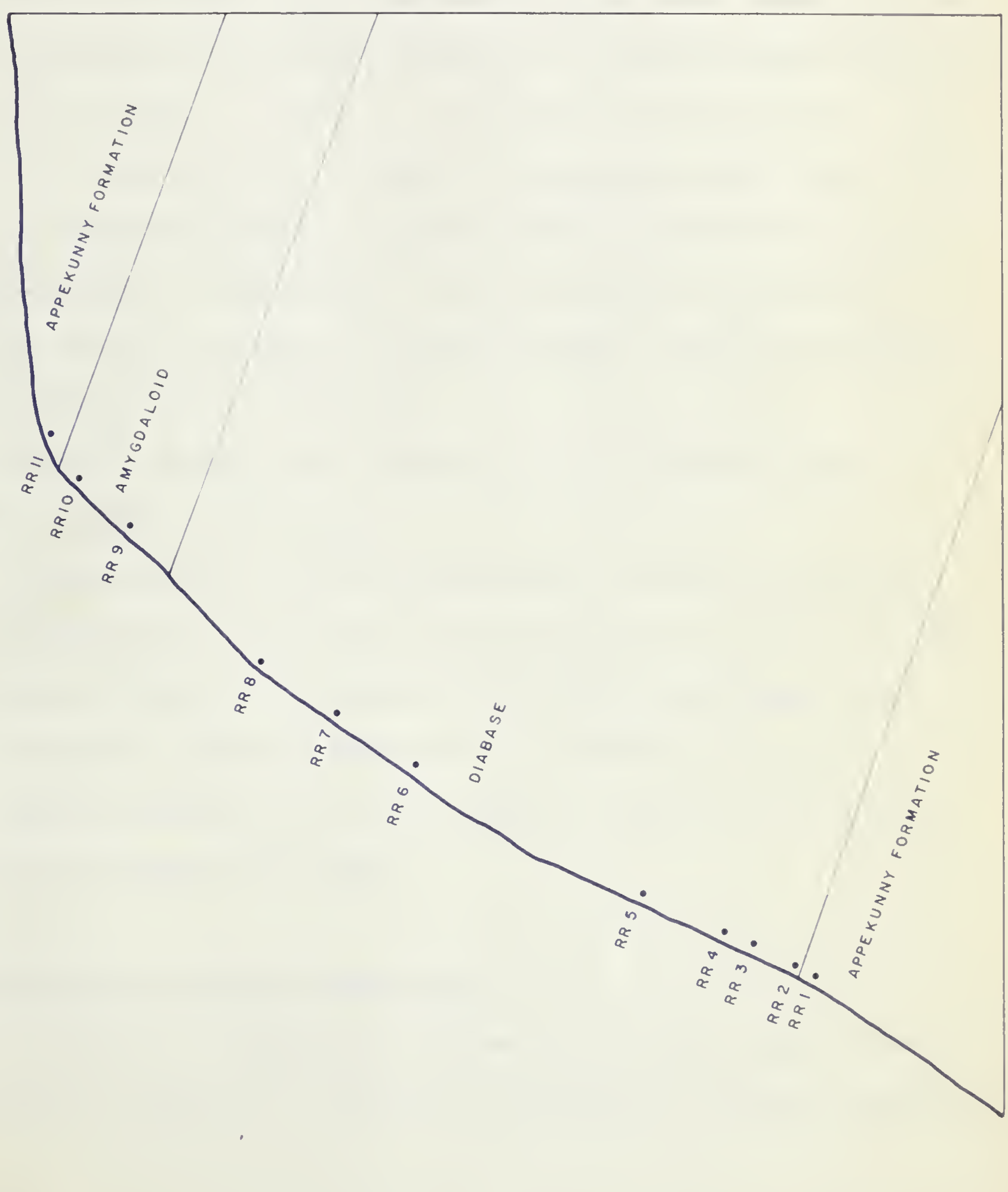


FIGURE 6
RUBY RIDGE SECTION
LOOKING SOUTH

0 FEET 10

Petrography of the Ruby Ridge Section

Vesicular amygdaloid, made up of plagioclase feldspar, chlorite and iron oxides, is present in the upper 8 feet of the flow (see Figure 6). The lower 42 feet of rock is composed dominantly of pyroxene and plagioclase feldspar having a diabasic texture.

The pyroxene of the flow is titaniferous augite that surrounds and encloses the feldspar laths. The reddish brown augite grains are about 1.0 mm. in length and the optical properties are: pleochroism and index of refraction X = 1.692, Y = 1.696, Z = 1.705; 2V = 50°, optically (+), C to Z = 27°. The composition of the augite is $Ca_{42}Mg_{38}Fe_{20}$ (after Hess, 1949).

The plagioclase laths are highly altered to saussurite and have a considerable range in composition. The larger grains, up to 50 mm. in length, are zoned in composition from An_{75} to An_{38}. Some of the smaller grains of plagioclase are oligoclase.

Quartz is present, but is found along with chlorite in the amygdules near the top of the flow.

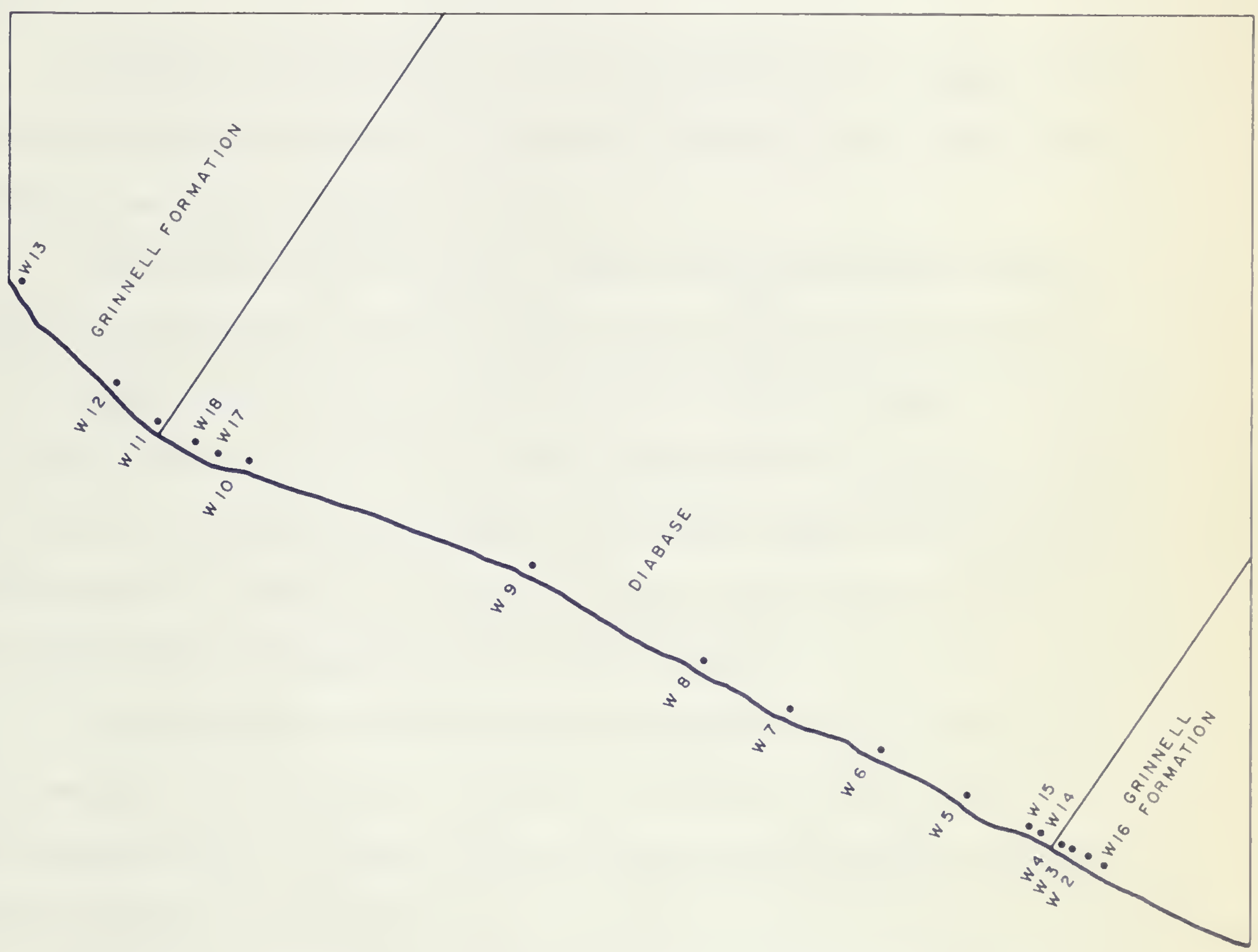
Secondary minerals include large amounts of chlorite, magnetite, calcite and saussurite. Some brown biotite occurs near the top of the flow. A few patches of chlorite and magnetite form olivine pseudomrophs (see Plate 3, Figure 4). Titaniferous magnetite is altered to leucoxene.

Accessory minerals are acicular apatite needles up to 1.0 mm. in length, pyrite, hematite and sphene.

Petrography of the Blakiston Brook Section

A dark green, medium-grained diabase flow, 50 feet thick, occurs in the Grinnell formation on Blakiston Brook (Figure 7). Sample locations

FIGURE 7
BLAKISTON BROOK SECTION
LOOKING WEST
0 FEET 10



and thin sections are given in Appendix A. Malachite and chalcopyrite occur along the chilled margin at the base of the diabase. In the upper, amygdaloidal portions of the flow, large plagioclase laths, up to 80 mm. in length, form a glomeroporphyritic texture (Grout, 1940, p. 81).

The average mineralogic composition of the Blakiston Brook diabase is: olivine pseudomorphs 7 per cent, pyroxene 17 per cent, plagioclase 24 per cent, secondary minerals 33 per cent, varietals and accessories 19 per cent.

The olivine pseudomorphs are very conspicuous in the upper parts of the flow between the stellate feldspar laths and form up to 10 per cent of the rock (see Plate 5, Figures 3 and 4).

The pyroxene is the typical, reddish-brown titaniferous augite variety, characteristic of these diabase flows. The optical properties of the augite taken near the center of the flow are: X = 1.686, Y = 1.690; Z = 1.705, C to Z = 54°; 2V = 45°. The composition is $Ca_{39}Mg_{44}Fe_{17}$ (after Hess, 1949). The optical properties of the augite taken near the top of the flow are: X = 1.701, Y = 1.708, Z = 1.719; C to Z = 20°; 2V = 47°. The composition is $Ca_{36}Mg_{30}Fe_{34}$ (after Hess, 1949).

The plagioclase feldspar varies in composition from labradorite to oligoclase but is generally difficult to identify in thin section. Some potash-feldspar is present near the base of the flow but is absent in the upper parts of the flow.

Secondary minerals are common throughout the rock and include saussurite, calcite, chlorite, quartz, biotite and serpentine. The plagioclase feldspars are masked by an aggregate of saussurite, sericite and chlorite. Ilmenite is altered to leucoxene. Serpentine and magnetite make up olivine pseudomorphs. Some chlorite and quartz occur in amygdules.

Accessory minerals include magnetite, ilmenite, pyrite, pyrrhotite, sphene and apatite.

Petrography of the Ruby Ridge and Blakiston Brook Contact Rocks

A well defined hornfels is produced in the quartzite country rocks below the lower contacts of the Ruby Ridge and Blakiston Brook flows. No hornfels was observed above the upper contacts of these igneous rocks but the upper contacts are poorly exposed.

The lower, fine-grained, equigranular contact rock of the Ruby Ridge lava is composed of interlocking quartz grains, minor amounts of feldspar and fine-sand sized rock fragments set in a chloritic matrix. Pyrite cubes, about 1/2 inch in size, are well developed at the contact. Very fine-grained calcite forms patches and stringers.

A light-green, hard, compact, sericite-chlorite hornfels is formed in the Grinnell argillite below the base of the Blakiston Brook flow. The thermal metamorphic effect of the flow may be traced into the sediments over a distance of at least 3 feet from the lava, by the presence of sutured intergrowths of the recrystallized, equigranular quartz grains.

Mount Rowe Section

R.J.W. Douglas (1952) in the Waterton map-area (Figure 5) mapped Purcell lava 200 feet thick at the top of the Siyeh formation. He described it as a dark, purplish-green basalt flow which contained amygdules of calcite and quartz.

The writer mapped a lava section at the top of the Siyeh formation on Mt. Rowe in Waterton Park and found that the Purcell lava could be divided into a number of thin flows. This division is based largely on

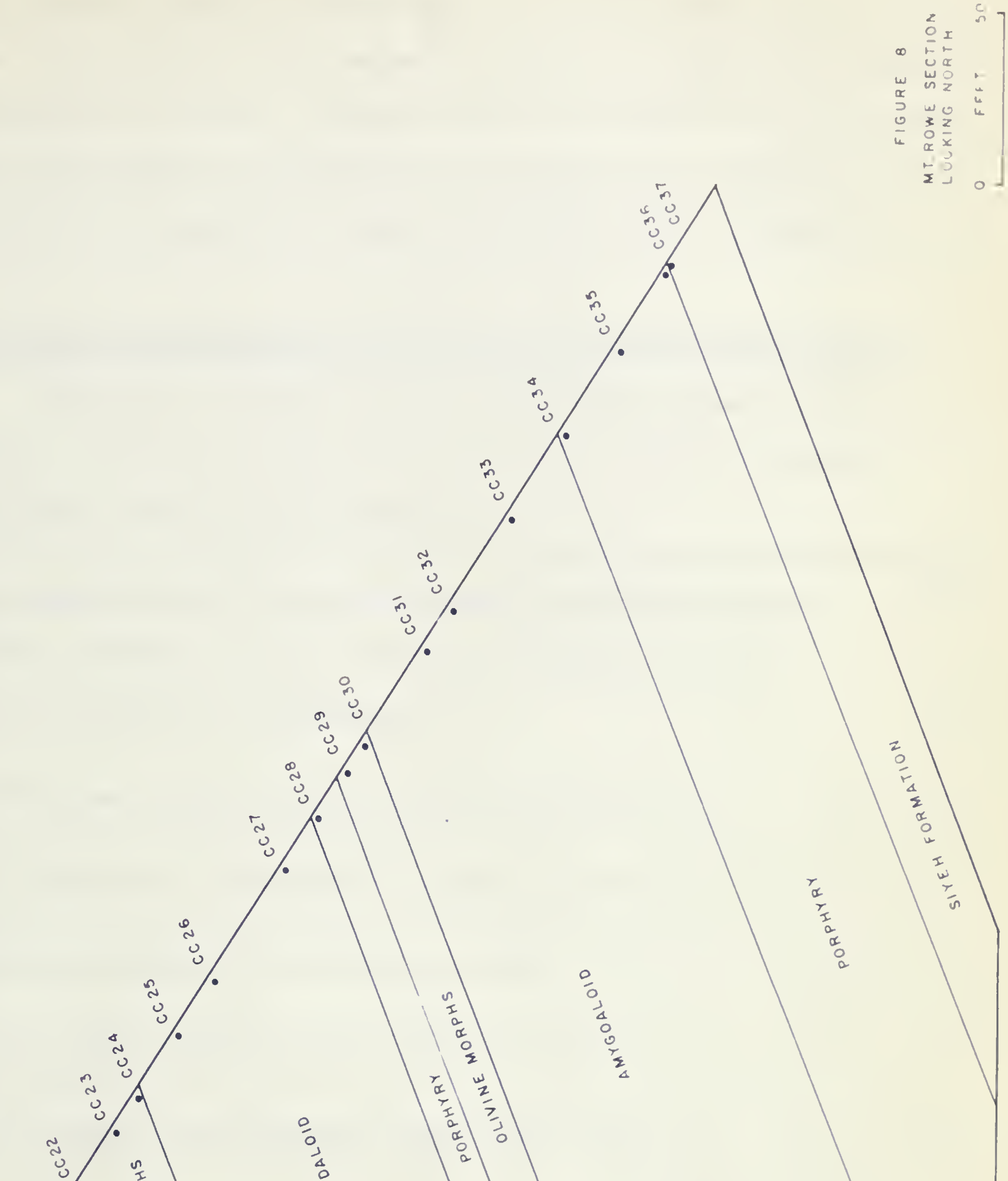


FIGURE 8
MT. ROWE SECTION
LOOKING NORTH

colour, attitude and constituents of the flows. In some places the units merge together and it is very difficult to place the exact contact between them. Near the base of the formation there may be a few feet of sediments intercalated in the flow. The basal part of the flows have incorporated small accumulations of sediments and are ellipsoidal in shape but the structures are indistinct. Sample locations are shown in Figure 8.

Purcell Lava section measured along east slope of Mount Rowe, Alberta

Sharp and conformable contact with Sheppard formation, which consists of green-weathering, thinly-laminated, silty and dolomitic argillites; and interbedded dolomites.

	Feet
Green, highly vesicular and amygdaloidal lava, irregular upper contact with flow structures, vesicles and amygdules up to 6 inches in length, some pipe-shaped.	20
Greyish-green, slightly vesicular and amygdaloidal lava.	30
Green and purple, medium-grained, amygdaloidal lava.	75
Purplish, amygdaloidal and porphyritic lava.	10
Purplish green, vesicular and amygdaloidal lava.	15
Green to purple, medium-grained amygdaloidal lava.	85
Purple and light green amygdaloidal and porphyritic lava, brecciated sediment with indistinct ellipsoidal structures.	50
Total thickness	285

Sharp, irregular, conformable and highly contorted contact with Siyeh formation which consists of light green, laminated, dolomitic argillites.

In thin section the amygdaloidal and porphyritic lavas are composed of altered, sericitized plagioclase feldspar (varying in size from less than 1 mm. to 10 mm. in length) in an aphanitic groundmass largely composed of chlorite and altered iron oxide minerals (see Plate 3, Figure 1). Sodium cobaltinitrite stained much of the groundmass yellow. The amygdules are filled with fibrous quartz, chlorite, hematite and in places calcite and barite. Chlorite makes up the interstitial space between the plagioclase, and replaces grain forms which resemble relict olivine. Some of the chlorite may have replaced a devitrified glass. Leucoxene and opaque iron minerals make up to 15 per cent of the rock.

Castle River Area

The Geological Survey of Canada has published to date three maps which show in detail the occurrence of the Purcell lava formation near the headwaters of Castle River. These exposures are the farthest north and the thickest accumulations of lava which outcrop in the Lewis series.

C.O. Hage (1940) mapped a dark green to purplish, vesicular and amygdaloidal basalt 350 feet thick between the Siyeh and Sheppard formations in the Beaver Mines area. The vesicles in the lavas were filled with calcite, quartz, pyrite and less commonly, barite and chalcopyrite.

D.K. Norris (1959) in the Carbondale map-area, studied a dark green and purplish-green amygdaloidal andesite and pillow andesite 295 feet thick, which he called the Purcell lava.

FIGURE 9
GEOLOGIC SKETCH MAP
CASTLE RIVER, ALTA
LAVA OUTCROP _ _
(AFTER GSC MAP 5-1959)
0 MILES 1

R.A. Price (1959) mapped a dark green and purplish-green, chloritized amygdaloidal andesite and pillow andesite, 320 feet thick. He noted a 30 foot zone of chloritized andesite pillow lava in a matrix of chloritized 'tuff-breccia' at the base of the Purcell lava formation.

Castle River Section

The writer measured a lava section on the south Castle River. Sample locations are shown in Figure 9.

Purcell lava section measured along south slope of Whistler Mtn., Alberta

Sharp, irregular and conformable contact with Sheppard formation which consists of greenish-grey dolomite, green siltstone and sandstone.

	Feet
Dark green and purplish-green, vesicular, amygdaloidal and microporphyritic lava.	280
Light green with red blotches, amygdaloidal and vesicular lava, with pronounced ellipsoids consisting of pillow lava and "balled-up" sedimentary accumulations about 2 feet in diameter.	20
Total thickness	300

Sharp contact with Siyeh formation which consists of rusty-weathering, baked and highly contorted argillaceous quartzites at the top; grading into red, green and grey argillites, and grey algal dolomites.

In thin section the highly altered amygdaloidal lava is of medium-grain size, in places microporphyritic, and contains euhedral plagioclase. The essential constituents surrounding the amygdules are altered plagioclase feldspar, chlorite and an opaque groundmass. Highly altered plagioclase, varying from albite to andesine, makes up most of the rock. Twinning is poor and alteration products have nearly obliterated the feldspar laths. There appears to be two generations of feldspar. The smaller, later-formed grains are much fresher than the larger grains (1.0 mm. in size) but identification is difficult. Chlorite and iron oxide minerals are interstitial to the plagioclase. Leucoxene is very common. The amygdules consist of chlorite, quartz and calcite. Some pyrite and barite are present as infilled material (see Plate 3, Figure 5).

GALTON SERIES

The Purcell lava formation is not exposed on the eastern half of the Galton range and not in the whole of the MacDonald range along the International Boundary (Daly, 1912, p. 213). Daly noted that at the summit of the Galton range the lava is faulted, and to the east of this fault the lava is eroded over a distance of about 35 miles.

Daly (1912, p. 213) gave the following section of the lava formation as found near the east side of the Kootenay River. Daly measured 10 complete sections of lava and found the average thickness to be close to 400 feet.

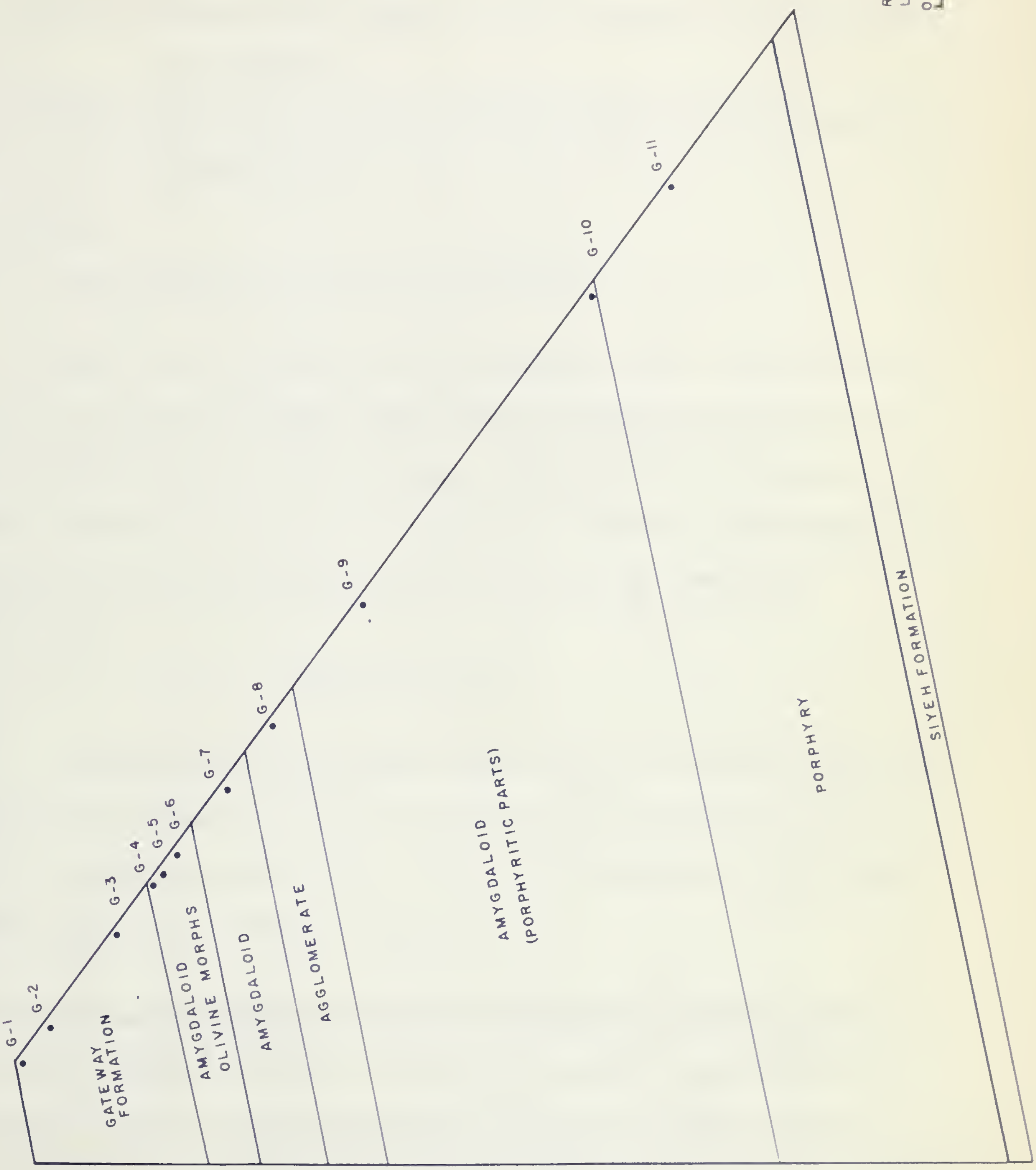


FIGURE 10
ROOSVILLE SECTION
LOOKING SOUTH

0 FEET 100

Top, conformable base of Gateway formation

d. 60 feet - greenish-black amygdaloid.

c. 40 feet - coarse basic breccia.

b. 200 feet - greenish-black amygdaloid with occasional large phenocrysts of labradorite.

a. 90 feet - porphyritic, non-vesicular, with abundant large phenocrysts of labradorite.

390 feet

Base, conformable top of Siyeh formation.

Zones a and b are part of one eruption of lava. The breccia may be of local extent since Daly noted an equal thickness of amygdaloid had replaced this zone c in other sections. The upper flow of amygdaloid or zone d appears to be a later flow than zone b. However, most of the lava is homogeneous, massive and may have formed from one great flow.

Roosville Section

The writer measured a Purcell lava section on Phillips Creek about 2 miles east of Roosville, B.C. This section may have been the same section as measured by Daly (1912, p. 213) but the thicknesses vary in part. Figure 10 shows the location of samples.

Purcell lava section measured along the north slope of Phillips Creek

Sharp and conformable contact with Gateway formation which consists of light grey to buff-coloured quartzites, dolomites and algal dolomites.

	Feet
Purplish to green coloured, sheared, amygdaloidal and vesicular lava, pipe amygdules up to one foot in length, specularite, malachite and abundant iron staining near the top of the formation, sharp and conformable contact with agglomerate.	75
Light greenish-grey, agglomerate of sedimentary silt and angular phenoclasts of basaltic amygdaloid, varying in size up to 2 inches in diameter.	35
Dark green and purplish-green, amygdaloidal and vesicular lava, microphenocrysts of plagioclase in part.	235
Light to dark green, amygdaloidal and porphyritic lava, light green plagioclase phenocrysts up to 3 inches in length.	140
Total thickness	485

Conformable contact of Siyeh formation, which consists of purplish, thin-bedded, dolomitic argillites.

In thin section the amygdaloidal flow rocks are always altered and consist essentially of plagioclase feldspar, chlorite and iron oxides (see Plate 3, Figure 3). The amygdules make up to 50 per cent of the rock and consists of chlorite, limonite, chalcedony and calcite. The plagioclase feldspar consists of different types, ranging from andesine to albite. Many of the larger grains (25 mm.) of plagioclase are completely albitized, and chlorite has replaced much of the tabular laths. Secondary minerals make up a large percentage of the specimens. They include chlorite, kaolin, sericite, calcite and leucoxene. Relict grains of olivine are completely replaced by chlorite and magnetite. Interstitial chlorite, iron opaques and plagioclase are commonly arranged in a texture. Patches of leucoxene may

form up to 10 per cent of the rock.

The agglomerate contains a mixture of equal amounts of sedimentary silt-sized material and phenoclasts of amygdaloidal lava.

PURCELL SERIES

Type Section Area

Daly (1912, p. 207-212) described the Purcell lava formation in three different areas within the Purcell Mountains. The lava thickens from the Galton range to the Purcells and this suggests that the source of eruption may be in the Purcell range. Apparently all the Purcell lava flows were extruded from fissures on the sea floor.

The Purcell lava formation is found about 5 miles east of the main fork of the Yahk river in the McGillivrary range of the Purcell Mountains. Daly's data (1912, p. 210) is as follows:

Top, conformable with base of Gateway formation

Second lava-flow:	f.	65 feet - amygdaloidal lava poor in phenocrysts.
Inter-bed:	e.	4 inches - argillite
	d.	150 feet - amygdaloidal lava poor in phenocrysts
First lava-flow	c.	200 feet - highly porphyritic, non-vesicular lava
	b.	10 feet - compact lava
	a.	40 feet - brecciated 'aa' lava

Total lava ----- 465 feet

Base, conformable with top of Siyeh formation

The thin section description given by Daly is as follows:

<u>Zone a</u>: Brecciated lava consists of fragmental masses of lava and sediment, resembling material from a volcanic explosion. Daly concluded that the

basal portions of the lava incorporated soft mud as it ran over the sea floor.
Zone b: Compact vesicular basalt, chilled in the lower parts, merging upward into porphyritic phase c. The dark grey-green lava of zones a and b is composed of labradorite (0.5 to 0.8 mm. in length), magnetite, chlorite and opal. Daly thought that most of the rock was originally a basic glass.
Zone c: The grey-green, non-vesicular and porphyritic lava is composed of greenish-coloured, altered, labradorite phenocrysts (1 to 3 cm. in length), embedded in a base of chlorite, leucoxene, green mica and smaller grains of labradorite (1.0 mm.).
Zone d: Blackish green, compact, homogeneous and highly amygdaloidal lava is composed of labradorite (1.0 mm. in length), chlorite, magnetite, leucoxene and limonite. The chlorite may have derived from pyroxene or a glass. Some small angular fragments of quartzite, metamorphosed argillite were observed along with an occasional large labradorite phenocryst. The amygdules (8 cm. in length), oriented parallel to the surface of the flow are composed of quartz, chlorite and sometimes green biotite.

Leech (personal communication) mapped two distinct lava zones separated by sediments at the type section area. Leech also noted that there are thinner lavas higher in the section, some of which Daly did not see and others of which he interpreted as faulted segments of a single lava zone.

Another Purcell lava section examined by Daly is exposed about 12 miles west of Gateway. Here he found a section similar to the type section. The lower brecciated zone is 20 feet thick and includes blocks of quartzite and metargillite. The whole formation, 500 feet thick, is made up of grey-green amygdaloid which appears to have replaced the porphyritic

phase of the type section. Nearby, the porphyritic zone is evident but the section is thinner and no sediments are present.

At the Kootenay River flats the lava section is composed of three members of the type section area, a highly scoriaceous amygdaloidal flow (50 feet thick) about 220 feet below the characteristic basal brecciated zone and an amygdaloidal rhyolitic flow (20 feet thick) occurring 50 feet above the top of the Purcell amygdaloid.

In thin section the rhyolite is seen to consist of kaolinized orthoclase and oligoclase phenocrysts in a groundmass of sericite, feldspar, quartz, apatite, leuxocene and rutile and allanite. The amygdules are filled with quartz and chlorite.

Cranbrook Area

S.J. Schofield (1915) in the Cranbrook map-area described two Purcell lava sections on Baker Mountain and Gold Creek in which he noted several flows interbedded in the Siyeh formation.

Towards the top of the Siyeh formation on Baker Mountain, located about 5 miles southeast of Cranbrook, Schofield (1915, p. 35) recorded the following Purcell lava section.

	Feet
Purple and green metargillites and sandy quartzites	20
Porphyritic-amygdaloidal basalt	50
Purple and green metargillites and sandy quartzites	50
Non-amygdaloidal, non-porphyritic basalt	100

	Feet
Purple and green metargillites	400
Amygdaloidal basalt	300
Purple and green metargillites and sandy quartzites	
Remainder poorly exposed	
Total thickness	920

Schofield (1915, p. 35, 78) noted that the lava flows are succeeded at the immediate contact by a sandstone composed of particles, generally angular, of the underlying basalt.

Schofield (1915, p. 76) described the Purcell lava section exposed on Gold Creek, about 10 miles south of Cranbrook, B.C. He gave the following section, approximate thicknesses and mineralogy:

	Feet
Rust brown weathered, dark green to black, amygdaloidal basalt, numerous amygdules filled with fibrous quartz, calcite and hematite.	30
Amygdaloidal-porphyritic basalt	25
Greyish-green, porphyritic basalt, consisting of labradorite phenocrysts (varying in size from less than one inch to 1 1/2 inches in length), embedded in a groundmass of labradorite and decomposed hornblende, zoisite and epidote.	50
Brecciated basalt, composed of angular and subangular masses of amygdaloidal-porphyritic basalt and some solidified surface material.	25
Total thickness	130

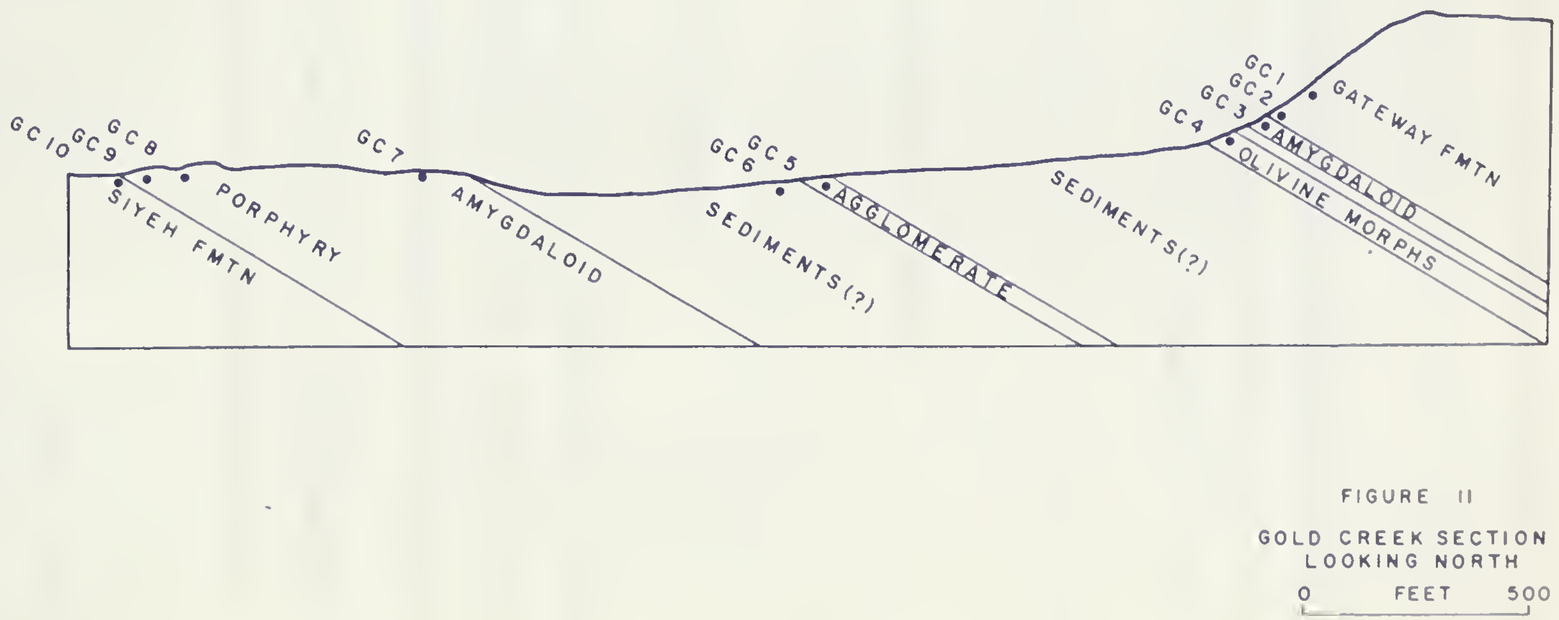


FIGURE 11

GOLD CREEK SECTION
LOOKING NORTH

Gold Creek Section

The writer measured a Purcell lava section near a logging road which crosses Gold Creek twelve miles southeast from Cranbrook. See Figure 1 for location of section and Figure 11 for location of samples.

Purcell lava section measured along north side of Gold Creek, B.C.

Sharp and conformable contact with Gateway formation which consists of purplish-coloured argillites, quartzites, dolomites and algal dolomites, with abundant salt casts.

	Feet
Dark-green, highly-altered amygdaloidal basalt.	35
Covered interval.	25
Purplish-green, non-amygdaloidal basalt.	50
Light green, thinly-laminated, dolomitic argillites; a very fine-grained sedimentary rock consisting of angular basaltic phenoclasts occurs near the middle of this poorly exposed part of the section.	900
Rusty brown weathered, dark green to black, amygdaloidal and porphyritic basalt, brecciated with indistinct ellipsoidal structures near the base.	400
Total thickness	1410

Sharp, contorted and conformable contact with the Siyeh formation, consisting of dark to light greenish-grey, dolomitic argillites.

In thin section the porphyritic and amygdaloidal lavas consist of highly altered plagioclase feldspar in a groundmass consisting mostly of chlorite and iron oxides. Amygdules make up to 60 per cent of the rock and are filled with quartz, chlorite, and calcite. The sericitized plagioclase laths (up to 10 mm. in length) can not be identified accurately but appear to be albite in composition. Sodium cobaltinitrite stained the potassium-bearing alteration products of the plagioclase yellow. Some chlorite occurs diseminated in the plagioclase grains. Large amounts of chlorite occur between the plagioclase grains in a relict diabase texture, but relict grain boundaries of the chlorite are indistinct. Iron oxides and leucoxene form up to 25 per cent of the rock.

In the Cranbrook map-area, Rice (1937, pp. 13-14) described the Purcell lavas which are found interbedded with the Siyeh argillites and a few purple and green tuff beds. He noted that no other volcanic rocks are known in the area. He stated, "The Purcell lavas vary in composition between andesite and diabase, the former being the more common. They are generally massive, green, fine-grained rocks, commonly amygdaloidal, and occur in individual flows from 1 to 30 feet thick. They are always considerably altered, the ferromagnesium minerals being completely changed to chlorite and epidote. The plagioclase is, however, recognizable in some cases and consists of andesine with a composition of about An 37 per cent. Hematite in large segregations 3 inches or more in diameter is common. Other constituents occurring in small amounts are magnetite, pyrite, quartz, calcite, colourless mica, garnet, apatite, and possibly orthoclase. The amygdules consist of calcite, quartz, chlorite and hematite."

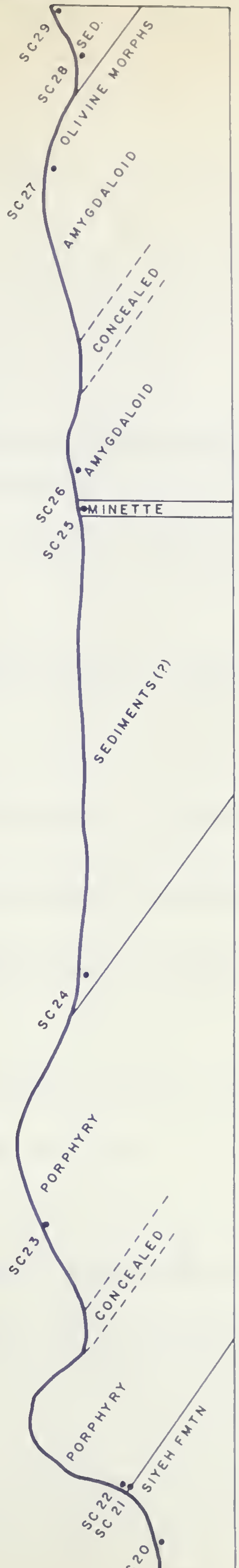


FIGURE 12
SKOOKUMCHUCK CREEK SECTION
LOOKING NORTH
0 FEET 100

Skookumchuck Creek Section

The writer measured the two most northern exposures of the Purcell lava in the Purcell series, Skookumchuck Creek and Lussier River. Sample locations are shown in Figures 12 and 13.

Purcell Lava section measured along the east side of Skookumchuck Creek

Sharp, irregular and conformable contact with the Gateway formation which consists of purple, green and grey, thinly-laminated, dolomitic argillites.

	Feet
Light purplish grey, altered, sheared, amygdaloidal basalt.	90
Concealed interval.	20
Light greyish-green, medium-grained, amygdaloidal basalt.	50
Dark brownish-grey, coarse-grained, lamprophyre.	10
Light greyish-green, thinly laminated dolomitic argillites; green and purple tuff beds.	190
Light green, amygdaloidal and porphyritic basalt; indistinct ellipsoidal structures near the base.	210
Total thickness	570

Sharp, irregular, conformable and contorted contact with the Siyeh formation which consists of light grey to green, laminated argillites.

In thin section the altered amygdaloidal and porphyritic lavas are composed of highly altered plagioclase feldspar, chlorite and leucoxene. Some of the larger plagioclase phenocrysts appear to be andesine in composition but alteration has obliterated and completely masked the tabular, poorly-twinned laths (see Plate 3, Figure 2). Chlorite patches with magnetite form grains which have the shapes of former olivine grains. Much of the skeletal and needle-shaped iron oxides are coated with leucoxene. The pipe-shaped amydules are filled with fibrous quartz, calcite, chlorite and rarely specularite.

The minette dyke which cuts the lava is composed of biotite, orthoclase and minor amounts of quartz, augite, hornblende, chlorite, calcite and epidote (see Plate 2, Figure 1). Accessory apatite, hematite, sphene and rutile are common.

Lussier River Section

Purcell lava section measured along the east side of Lussier River

Sharp, and conformable contact with the Gateway formation which consists of light to dark grey, laminated dolomitic argillites.

	Feet
Dark green to black, schistose, amygdaloidal basalt.	35
Rusty-weathered, dark greyish-green, very thin bedded argillites and intercalated tuff beds. A massive, thick bed of mixed sedimentary and volcanic material occurs near the top of this part of the section.	340

FIGURE 13

LUSSIER RIVER SECTION
LOOKING NORTH

0 FEET 100

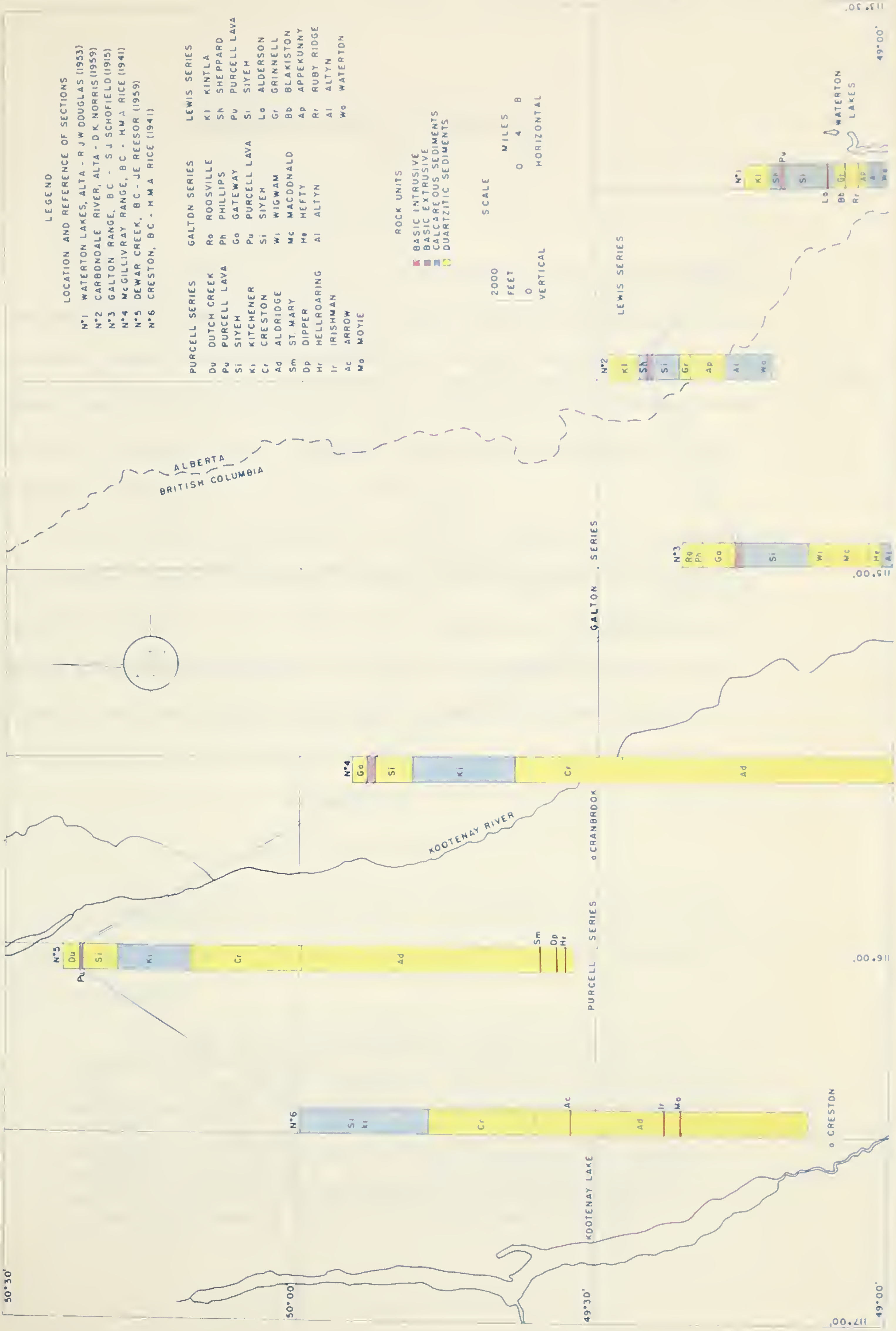
	Feet
Dark grey weathered, greenish-grey, amygdaloidal and porphyritic basalt, indistinct brecciated structures near the base.	180
Total thickness	555

Sharp, contorted and sheared contact (fault zone) with the Siyeh formation which consists of light green, laminated argillites, few narrow quartz veins near upper contact.

In thin section the amygdaloidal and porphyritic lavas are composed of altered plagioclase feldspar laths (up to 10 mm. in length) embedded in a matrix consisting largely of chlorite and leucoxene. The amygdules which make up to 50 per cent of the rock are composed of chlorite, calcite and quartz. Some of the chlorite appears to have replaced olivine near the top of the section.

The sediments are made of very fine sand-sized material, including basaltic rock fragments. Quartz, plagioclase, muscovite, and chlorite make up most of the mixed sediments.

Figure 14. Distribution of Studied Purcell Eruptive Rocks



CHAPTER IV - INTRUSIVE PHASE

INTRODUCTION

Numerous intrusive bodies of basic igneous rock occur within the Proterozoic formations of the Lewis, Galton and Purcell series. These intrusions, which are found dominantly in the form of sills, are most abundant and thickest within the oldest sedimentary rocks in the Purcell Mountains (see Figure 14). Comparable sills occur in nearly all the Proterozoic formations of the Rocky Mountains.

In the Purcell Mountains the sills are composed of altered plagioclase feldspar, green amphibole, biotite and intergrowths of quartz and plagioclase feldspar. The sills of the Glacier-Waterton Park area are composed of altered plagioclase feldspar, titaniferous augite, brown amphiboles and granophyric intergrowths of orthoclase and quartz.

LEWIS SERIES

Glacier Park Area

G.I. Finlay (1902, p. 349) gave the following description for the intrusive "dioritic" igneous rocks, which he found in the Lewis series. He stated,

> "On Mount Gould and on Mounts Grinnell, Wilbur and Robertson there is found a band of diorite 60 to 100 feet thick. Near the upper and lower surfaces this intrusive sheet was chilled and is fine grained. In the centre the texture is medium or fine-grained. Several dikes which have acted as conduits for the molten rock are exposed in the region near Swift Current pass. One of these extends across the cirque occupied by the Siyeh glacier and runs vertically up the amphitheatral walls. It is 150 feet in width.

A second dike, vertical and 30 feet wide, comes in beside the Sheppard glacier. Along the trail to the east of Swift Current pass the diorite sheet breaks across the Siyeh argillite and runs upwards as a dike for 500 feet. It then resumes its horizontal position as an intercalated sheet between the beds of argillite. As a dike it skips for 600 feet across the strata on Mount Cleveland.

Under the microscope the diorite is found to contain abundant plagioclase, with small amounts of another feldspar, much weathered, which does not show twinning. This mineral is closely intergrown with quartz. Brown hornblende is the principal dark silicate. The plagioclase has an extinction angle high enough for labradorite but it gives no definite clue as to its exact basicity. No section of a fresh piece twinned on the albite and Carlsbad laws at the same time could be observed. The quartz is not present in sufficient amounts to make advisable the name quartz-diorite for the rock. The small patches of biotite originally present are entirely altered to chlorite. Pyrrhotite is occasionally met with, apatite occurs in crystals of unusual length, and magnetite in lath-shaped pieces is common."

C.P. Ross (1959, pp. 56-57) noted gabbroic igneous rocks in Glacier National Park which form narrow sills and dykes in the Siyeh limestone. Long, thin steeply dipping dykes occur from St. Mary Lake northwestward past Lake Sherburne (see Figure 4). In the Flathead region the intrusions are irregularly scattered, peculiar in composition and occur above the Siyeh limestone. Ross gave the following petrographic notes on the intrusive rocks. He stated (p. 56), "the rocks are composed principally of titaniferous augite, largely altered to hornblende, and zoned plagioclase that ranges in composition from An_{75} at the core to An_{25} in some of the outermost zones. Some separate hornblende crystals may be of primary origin. Most of the plagioclase is decidedly calcic. In addition, some potash feldspar, micropegmatitic intergrowths of quartz and alkalic feldspar, minor amounts of quartz, apatite and opaque iron oxides and such alteration products as sericite, chlorite,

and calcite, are present. Exceptionally, potash feldspar is sufficiently plentiful to color the rock pink. The rock has diabasic texture, obscured, however, by alteration products and interstitial micropegmatite, which commonly constitutes 10 to 20 per cent of the whole and which is locally more abundant."

Petrography of Logan Pass Sill

The writer studied a thin sill exposed about one-quarter mile east of the summit at Logan Pass, Montana (see Figure 4). This dark greenish-grey coloured, fine to medium-grained diabase sill is composed mainly of pyroxene, amphibole, plagioclase, orthoclase and quartz.

The pyroxene is reddish brown, titaniferous augite and occurs mostly in the chilled-borders of the sill. Within the main part of the sill, the augite is rare to absent. The augite is subhedral, twinned and surrounds the plagioclase laths. Some of the augite is altered to secondary minerals. The optical properties of augite are: 2V = 52°, optically (+), C to Z = 45°.

The amphibole consists of primary brown hornblende and secondary green amphibole. Some of the amphibole is altered to biotite and chlorite (see Plate 6, Figure 8). The optical properties of the two amphiboles are:
brown hornblende: pleochroism and index of refraction X = light brown 1.660, Y = red brown 1.674, Z = red brown 1.677; 2V = 50°; optically (-); C to Z = 15°.
green amphibole: pleochroism and index of refraction X = light green 1.656, Y = green 1.668, Z = dark green 1.674; 2V = 70°; optically (-); C to Z = 14°.

The feldspar of the diabase is zoned plagioclase (1.0 mm. in length), and minor blebs of pink orthoclase. The plagioclase laths, varying in composition from labradorite to oligoclase are altered and poorly twinned. Most of the orthoclase occurs as minute wedge-shaped forms in a granophyric intergrowth with quartz (see Plate 4, Figure 2).

The secondary minerals biotite, chlorite, epidote, clinozoisite and sericite form up to 50 per cent of the rock. Chlorite has replaced former olivine grains near the contact zones.

Skeletal and octahedral grains of titaniferous magnetite, which is largely altered to leucoxene, may constitute to 15 per cent of the rock. Sulphides, apatite and sphene are the dominant accessory minerals.

Waterton National Park Area

Near the International Boundary, Daly (1912, pp. 214-215) described two dykes and two sills of basic composition in the Lewis series.

The vertical dykes (each about 20 feet thick) strike northwest and intrude sedimentary beds of the Appekunny and Grinnell formations. They are found north of Lower Kintla Lake. Daly concluded that those intrusives were feeders to the lithologically similar Purcell amygdaloid.

Near Upper Kintla Lake a greenish grey, fine-grained diabase to gabbroid sill occurs in the Siyeh formation about 1200 feet below the base of the Purcell lava. In thin section Daly noted the following constituents: diopsidic augite (0.1 mm. or less to 0.6 mm. in size), labradorite (0.2 mm. in length), green hornblende; micropegmatite of

quartz and orthoclase, skeletal, lath and octahedral-shaped magnetite, apatite, sphene, pyrite, epidote, chlorite, zoisite, limonite and calcite.

A badly altered, fine-grained sill, 50 feet thick, is found in the Siyeh formation on Cameron Creek (Daly, 1912, p. 215). Its constituents are as follows: augite, hornblende, labradorite, micropegmatite, epidote, chlorite, kaolin, sericite, saussurite and limonite. Daly (1912, p. 215) stated, "A specimen taken at a point five feet from the upper contact and thus representing the contact zones, bears no hornblende, but the bisilicate is entirely augite, crystallized, as usual, in apparently two generations. The hornblende, here, as in the other sill, has every evidence of being a primary constituent. It seems to have been able to crystallize only in the interior part of the sill, while augite monopolized the contact zones."

Petrography of Lake Alderson Sill

The writer studied a sill at Lake Alderson, in the Siyeh limestone, which may be the eastward extension of the sill described by Daly on Cameron Creek (Hunt, 1958). The Fentons (1937, p. 1904) pointed out that there were a number of intrusions at Lake Alderson where slightly crystalline, brownish green dykes cut the Siyeh sills. To the west they also noted that the Carthew dyke joins the Purcell lava in the cirque wall below Carthew Lakes (see Figure 1 for location).

The minerals of the diabase are as follows: pyroxene 20 per cent, amphibole 5 per cent, plagioclase 10 per cent, K-feldspar 8 per cent, secondary minerals 36 to 40 per cent, varietals and accessories 10 to 15 per cent.

The pyroxene is reddish-brown, titaniferous augite and is altered in part to amphibole. The amphiboles consist of both primary brown hornblende and secondary green amphibole.

The feldspar of the sill is plagioclase, varying in composition from labradorite to a less calcic feldspar, and minor amounts of orthoclase occur as granophyric intergrowths with quartz.

The secondary minerals include calcite, epidote, clinozoisite, kaolinite, sericite, chlorite and limonite. Titaniferous magnetite, surrounded by leucoxene, is found with accessory minerals sphene, apatite, pyrite and pyrrhotite.

Petrography of the Contact Rocks

The contacts of the sills with the Siyeh sediments at Lake Alderson and Logan Pass are a calc-flinta (Harker, 1932). Contact metamorphism produces a change in the Siyeh limestone over a zone up to a few feet in width. The calc flinta is green in colour, cherty-looking, and appears to be vesuvianite, epidote, wollastonite and garnet.

PURCELL SERIES

Dykes

Daly (1912, p. 212) studied a medium-grained gabbroid dyke (50 feet thick) cutting the Siyeh formation near the summit in the McGillivray range of the Purcell mountains. He considered this vent to be an important feeder for the Purcell lava since both rocks are lithologically identical. The dyke is composed of acid labradorite in a groundmass of chlorite, calcite, epidote, kaolin, muscovite, limonite, quartz and ilmenite.

Some chlorite has replaced former grains of amphibole and interstitial pyroxene.

Kingsgate, British Columbia

The intrusive sills found at Kingsgate, B.C. were first studied in detail by Daly (1912) and Schofield (1915). They referred to them as the Moyie sills, "A", "B", "C", "D". The writer worked on Sill "A", the highest in the series (Hunt, 1958). A well defined hornblende-biotite hornfels is developed at the upper contact of the sill, and the biotite from this zone was used for dating purposes (see Chapter VI0.

The mineral constituents of Sill "A" are: green actinolite 53 per cent, zoned plagioclase 10 per cent, quartz 5 per cent, secondary minerals 30 per cent and accessories 2 per cent.

Petrography of Arrow Creek Section

A basic igneous rock is exposed on the west side of Highway 95 about one mile south of the Arrow Creek bridge. The contacts with the surrounding sediments are not exposed in the road cut but adjacent outcrops of Aldridge sediments strike north and dip 20° to the west. The greater part of the outcrop is medium-grained but a vertical band approximately 15 feet wide is distinctly coarser (see Figure 15). The coarse-grained phase does not show distinct contacts with the medium-grained rock. The vertical band may be a dyke but the structural relations could not be determined. The sill is composed of green amphibole, altered plagioclase feldspar, quartz, saussurite, chlorite, muscovite, calcite and biotite with accessory sphene, ilmenite and apatite.

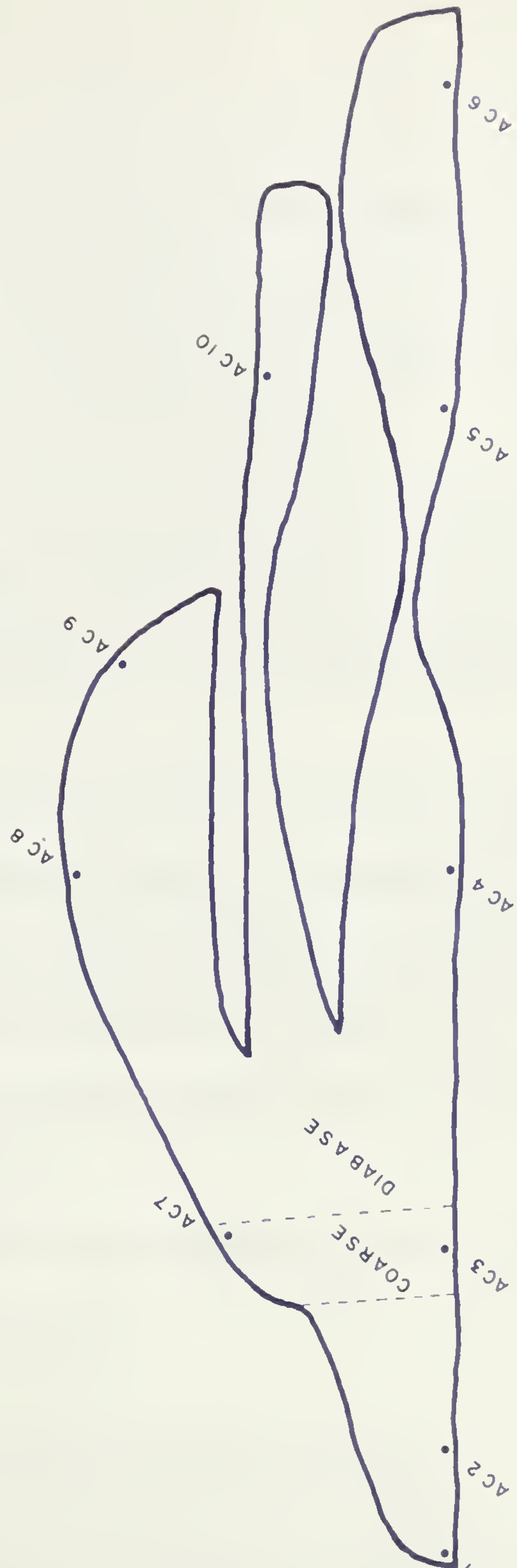


FIGURE 15
ARROW CREEK SECTION
LOOKING WEST
0 FEET 40

The amphibole is green, pleochroic, fibrous actinolite. It occurs as large, prismatic crystals that are usually twinned. The individual grains range in length from 1 to 5 mm. and average about 3 mm. They are poikilitic in part, and enclose or partly envelop small plagioclase grains. In some specimens the amphibole is replaced by secondary minerals such as chlorite, biotite and epidote. Optical properties of amphibole: X = yellow green 1.648, Y = olive green 1.664, Z = blue green 1.668; C to Z = 13°; 2V = 55°.

The plagioclase feldspar (about 1 mm. in length) is badly altered and varies in composition from labradorite to oligoclase. It is altered to kaolin, sericite, clinozoisite, epidote and carbonate. Twinning is rare and indistinct.

Quartz forms up to 20 per cent of the rock. Granophyric intergrowths of quartz and feldspar occur in cuneiform and radial textures.

Secondary minerals are alteration products of the feldspars and the mafics, and make up 10 to 30 per cent of the rock. Epidote and calcite form patches and veinlets. Some biotite is found around the edges of the amphibole grains.

Common accessories of the rock are sphene, leucoxene, magnetite, pyrite, pyrrhotite and hematite.

Irishman Creek, British Columbia

The writer studied a well-exposed, diabase sill in a freshly blasted cut of Highway 95 at Irishman Creek, B.C., which is about 33 miles southwest of Cranbrook. The location of the samples is shown in Figure 16.

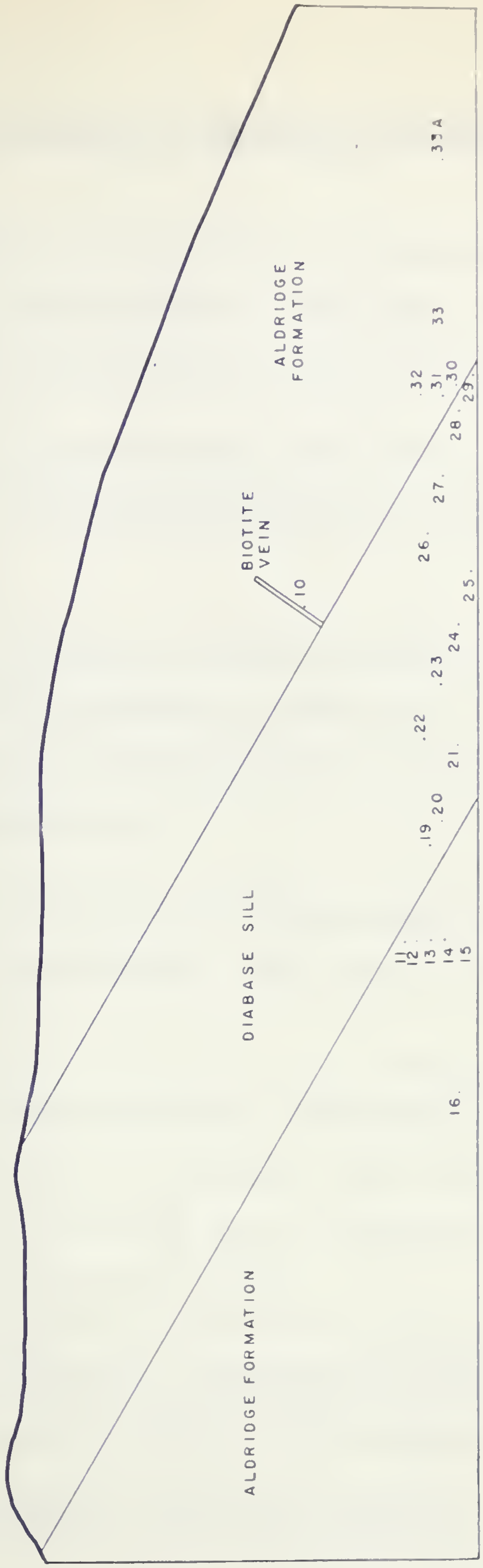


FIGURE 16
IRISHMAN CREEK SECTION
LOOKING NORTH

0 FEET 20

<u>Section measured along the northwest side of the road at Irishman Creek</u>

	Feet
Dark grey, thin-bedded, silty argillite; laminated beds varying in thickness from a few millimetres to a few inches; minor amount of quartzite; rock cleavage developed parallel to bedding.	70
Rusty weathering, light grey quartzite; some beds are up to two feet in thickness; a few blocky-weathering, argillaceous quartzite beds.	25
Medium grey, very thin-bedded to laminated argillite; cross-bedding well preserved; contorted and crumpled zone near upper contact with sill; narrow biotite-quartz vein extending from sill into sedimentary host rock.	4
Buff coloured, soft, bleached, hornblende-bearing, biotite selvage zone; sharp and conformable upper contact of sill with sediment.	1
Rusty-weathering, medium greyish green, medium-grained quartz diabase sill with chilled upper and lower margins; narrow quartz-rich veins criss-cross the upper portions of the sill; jointing is perpendicular to the top and bottom of the sill.	25
Buff coloured, soft, kaolinized, hornblende-rich selvage zone; conformable, knife-edge lower contact of sill with sediment.	1
Dark grey, very fine-grained, argillaceous quartzite.	4

	Feet
Succession of light and dark grey, argillaceous quartzite and blocky weathering, thick-bedded quartzites.	45
Greyish-brown weathering, medium-grey, very fine-grained argillites; some quartzite beds up to 2 feet thick.	30
Total thickness	205

The sill is composed of amphibole, plagioclase, quartz, biotite, secondary minerals, and accessories (see Figure 17).

The amphibole of the diabase is green, pleochroic, twinned and fibrous actinolite (see Plate 6, Figure 5). It usually occurs in plume-shaped crystals or euhedral laths 1 to 3 mm. long. The larger, poikilitic amphibole prisms in the upper part of the sill enclose or envelope feldspar and quartz grains. Some of the edges of the amphibole grains are altered to biotite. The optical properties of the amphibole are: pleochroism and index of refraction (average) - X = light yellow green 1.645, Y = medium green 1.648, Z = bluish-green 1.652; 2V = 70°; optically (-); C to Z = 18° (average).

The feldspar consists of zoned plagioclase which varies in composition from bytownite to oligoclase. The altered plagioclase occurs in poorly twinned, lath-shaped crystals and some grains show an inner calcic core (An_{75}) grading to an outer sodic rim (An_{30}). The composition averages (10 An content determinations per thin section) are plotted in Figure 17. Andesine feldspar would probably be the average plagioclase for the whole rock. The feldspar grains found at

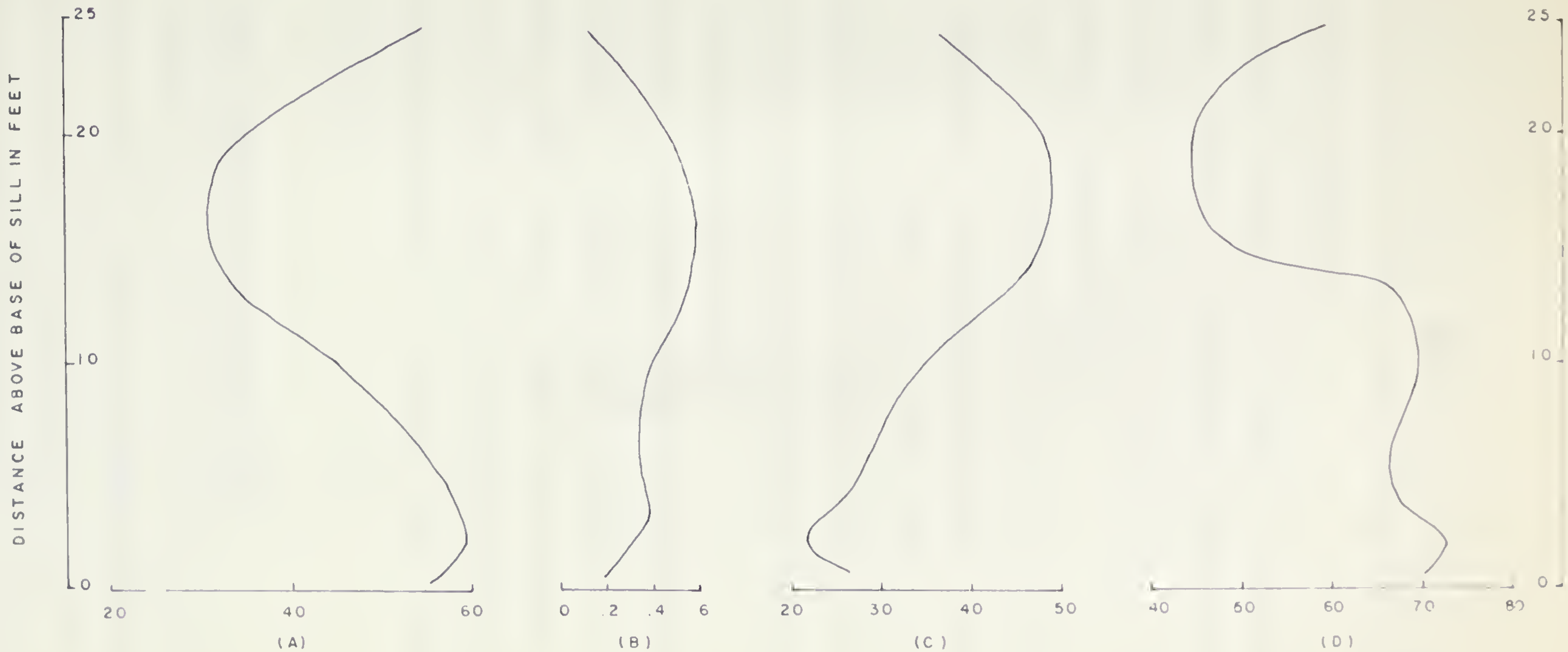


FIGURE 17 PETROGRAPHIC VARIATION IN IRISHMAN CREEK SILL

(A) AVERAGE PERCENTAGE AN-CONTENT OF PLAGIOCLASE
(B) MEAN LENGTH OF PLAGIOCLASE (MM)
(C) MODAL PERCENTAGE OF PLAGIOCLASE
(D) MODAL PERCENTAGE OF TOTAL MAFICS

the contacts of the sill (chilled margins) are usually low in anorthite content, but the presence of relict labradorite grains indicates an initially more calcic composition.

Quartz is always present and increases in grain size and amount near the upper part of the sill. Granophyric intergrowths of quartz and plagioclase are common in patches up to 1 mm. in size. Much of the quartz is unstrained and free from inclusions.

Brown biotite is abundant near the contacts and in the upper part of the sill. Texturally, the biotite at the contacts replaces some of the amphibole. Within the sill, where biotite forms over 20 per cent of the rock, it appears to be largely primary in origin. Most of the biotite flakes, up to 0.5 mm. in size, are fresh, but some have a pronounced sieve texture and are associated with chlorite.

Secondary minerals include alteration products of the feldspars and the mafic minerals. Common minerals are epidote, chlorite, clinozoisite, sericite, kaolin, biotite, quartz and leucoxene. Some of the plagioclase is completely replaced with the saussurite group of minerals.

Accessories are magnetite, ilmenite, sphene, apatite, pyrite, pyrrhotite and hematite.

Petrography of the Irishman Creek Contact Rocks

The unweathered, well exposed upper and lower sill-sedimentary contact zones were studied in order to establish the extent of the thermal effect by the sill on the argillaceous quartzites. Secondly, since the contact zone would be most susceptible to alteration, sub-

sequent metamorphic events in the area might be reflected in the mineralogy of this contact. Biotite from this contact zone was used for K-Ar dating (see Chapter VI). Both contacts at the margins of the sill are almost identical lithologically and mineralogically, so only the lower contact will be discussed in detail. Zero footage is taken at the base of the sill.

Zone 0"-4" - A buff-coloured, soft, gouge-like selvage zone is composed of quartz and feldspar (50%), biotite (15%), kaolinite material (15%), epidote (10%), chlorite (5%), sphene (4%) and minor accessories (1%).

Most of the rock contains a "kaolinized" mosaic of very fine-grained quartz, andesine and orthoclase feldspar grains. The plagioclase feldspar is altered and the most calcic grain gave a composition of An_{32}.

Brown coloured, tabular, fresh biotite flakes vary in size but some are over 0.25 mm. Chlorite and biotite have completely replaced amphibole prisms which are up to 0.5 mm. in length.

An abnormal amount of anomalous blue interference coloured epidote and patches of sphene are irregularily scattered throughout the sediment immediately adjacent to the sill.

Zone 4"-8" - This part of the contact rock is mineralogically similar to that described above except the amphibole has not been replaced. Pleochroic, poikiloblastic and twinned amphiboles

(up to 3 mm. in length) make up 25 per cent of the rock. The optical properties of the amphibole are: Pleochroism and index of refraction - X = light green 1.653, Y = medium green 1.662, Z = blue green 1.666; 2V = 70°; optically (-); C to Z = 13°.

Zone 8"-12" - Light to medium grey coloured, hornfelsic rock is composed mainly of a fine-grained equigranular, interlocking matrix of quartz and feldspar with larger blebs of biotite, muscovite and epidote scattered throughout. Chlorite, sphene, tourmaline and iron ores are present in minor amounts.

Cranbrook Area

In the Cranbrook area the Purcell sills have been well documented. The main occurrences of these sills are found in the following areas: St. Mary Lake, B.C. (Schofield, 1914, 1915; Leech, 1957; Hunt, 1958); Kimberley, B.C. (Jure, 1929; Swanson and Gunning, 1945; Scott, 1954); and in the general Cranbrook area (Rice, 1937, 1941).

At St. Mary Lake, Schofield (p. 74) noted the occurrence of the most basic type of Purcell sill. He stated (1914, p. 5), "The most basic type is hypersthene gabbro and occurs in one of the St. Mary sills. It is a dark grey, crystalline rock of granitic texture, in which can be detected plagioclase and augite. The rock is quite fresh, the feldspars being clear and glossy, a feature very rare in the basic

[illegible]

[illegible]

[illegible]

[illegible]

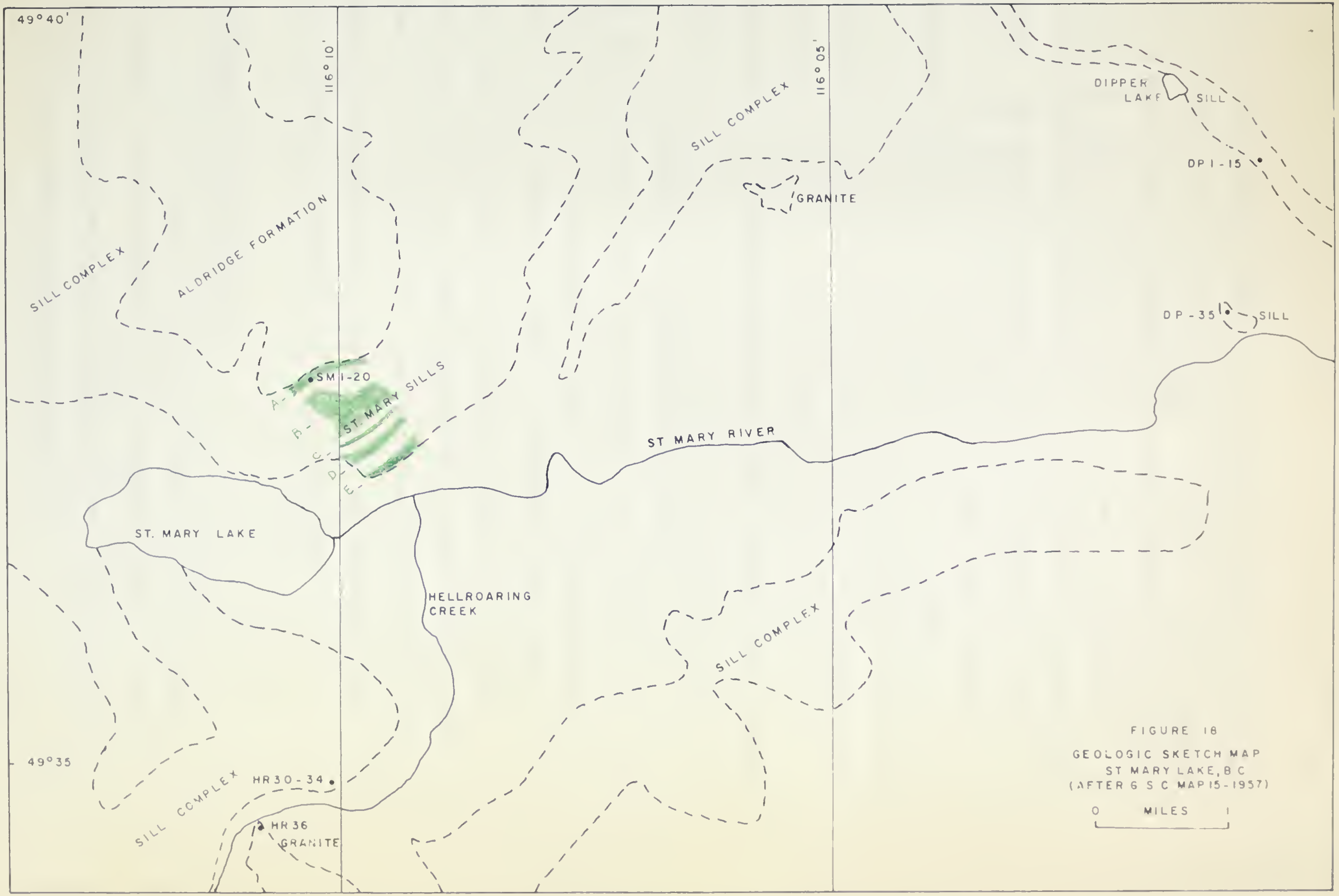


FIGURE 18
GEOLOGIC SKETCH MAP
ST MARY LAKE, B C
(AFTER G S C MAP 15-1957)

rocks of East Kootenay. Under the microscope, the essential constituents of the gabbro are seen to be labradorite and pyroxene. The labradorite occurs in lath-shaped individuals, which show carlsbad, pericline and albite twinning. Filling the interstices between the labradorite crystals occurs the pyroxene which is of two varieties, hypersthene and augite. The augite is colourless and without pleochroism. Uralitization in all stages is common in this rock; in many cases crystals of hornblende occur with a core of augite. Where the secondary hornblende is in contact with the labradorite it has the characteristic pleochroism, greenish-blue parallel to c, strong green parallel to b, and pale yellowish green parallel to a. This is worthy of notice as nearly all the hornblende in the hornblende gabbro is of this type and it also strongly supports the theory that all the hornblende is secondary in origin."

No pyroxene was recognized by the author (Hunt, 1958) in the St. Mary "A" and "B" sills at St. Mary Lake, B.C. The basal parts of the thick "B" sill were not sampled in detail due to the inaccessibility of this sill (see Leech, Map 15-1957). In 1959, the writer studied a dark green, medium-grained and well-exposed diabase sill (400 feet thick) which occurs near Dipper Lake and to the east of the St. Mary Lake "B" sill (see Figure 19). The lower third portion of the Dipper Lake sill was examined for pyroxenes (Turner and Verhoogen, 1960, p. 212) but no pyroxenes or pyroxene relicts were recognized.

Petrography of Dipper Lake Sill

The locations of sill samples and thin sections are shown on Figure 19. The constituents of the Dipper Lake sill are as follows: amphibole, plagioclase, quartz, secondary minerals, and accessories. Pyroxenes were absent throughout the entire sill.

[illegible]

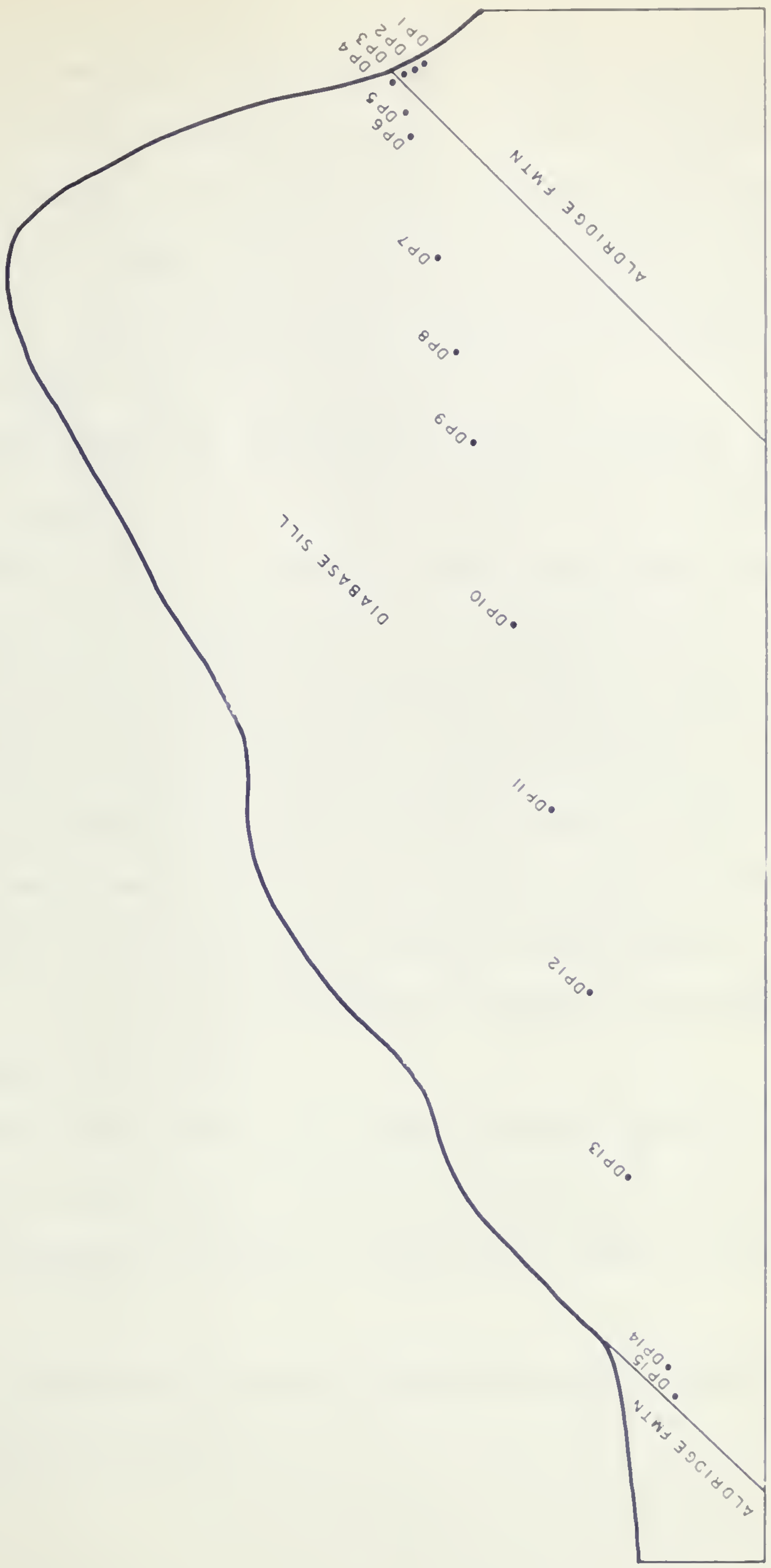


FIGURE 19
DIPPER LAKE SECTION
LOOKING SOUTHEAST

0 FEET 100

The amphibole is the familiar pleochroic, green, poikilitic, twinned, fibrous, radiating actinolite. Most of the grains are 1 mm. in size but in the upper parts of the sill, some grains are up to 5 mm. in length. The average optical properties of the amphibole are: X = light yellowish green 1.643, Y = olive green 1.658, Z = blue green 1.662; C to Z = 13°; 2V = 60°.

The feldspar of the diabase is made up of small, highly altered plagioclase laths, usually less than 1 mm. in length. The upper part of the sill is coarser-grained and contains larger plagioclase grains. The composition of the feldspar varies from albite in the margins of the sill to labradorite within the main part of the sill. There is very little fresh, twinned plagioclase; most of the grains are clouded with minerals of the saussurite group.

Quartz makes up to 15 per cent of the rock. It occurs with plagioclase to form patches of granophyric intergrowths. These intergrowths, up to 2 mm. in size are most abundant in the margins and upper portion of the sill.

Secondary minerals are largely epidote, kaolinite, sericite, zoisite and minor amounts of chlorite, biotite and leucoxene. Large granular patches and veinlets of epidote are common throughout the rock.

Accessories are sphene, apatite, magnetite, ilmenite, pyrite, pyrrhotite and hematite.

Hellroaring Creek, British Columbia

At Hellroaring Creek, an igneous and sedimentary complex, consisting of numerous diabase sills and intermixed Aldridge sediments, is intruded by a granitic stock and its pegmatitic off-shoots (Schofield, 1915, pp. 79-80). This stock may be the first reported granitic rock of post-Purcell and pre-Windermere age in the Purcell Mountains.

Petrography

Three quartz diabase sills of the Hellroaring creek complex were studied and found to be the normal hornblende gabbro type of Purcell sill (see Figure 18 for location of samples HR 30-34). A small, circular-shaped pegmatite, about 50 feet in diameter occurs on the north bank of Hellroaring Creek. Biotite which was developed at the contacts of the sill and the pegmatite was used for age-dating purposes. Muscovite (Sample HR-36, figure 18), from within the granitic stock was also prepared for a date (see Chapter VI).

The light grey, coarse-grained to pegmatitic stock is composed of quartz 30 per cent, albite 65 per cent, muscovite 3 per cent, with accessory potash feldspar, blue pleochroic tourmaline, apatite, and rounded, colourless garnet (see Plate 4, Figure 3).

TABLE 2. MODAL ANALYSES OF PRESENT STUDY ON BASIC IGNEOUS ROCKS

	EASTERN PURCELL						WESTERN PURCELL							
LOCATION	LOGAN PASS (SILL)	LAKE ALDERSON (SILL)	BLAKISTON BROOK (LAVA)	RUBY RIDGE (LAVA)	MT. ROWE (LAVA)	CASTLE RIVER (LAVA)	ROOSVILLE (LAVA)	ARROW CREEK (SILL)	IRISHMAN CREEK (SILL)	GOLD CREEK (LAVA)	DIPPER LAKE (SILL)	ST. MARY LAKE (SILL)	SKOOKUMCHUCK (LAVA)	LUSSIER RIVER (LAVA)
Number of thin sections	4	5	7	6	17	3	6	10	11	5	11	8	5	5
Amygdules (chlorite, quartz, calcite)	-	-	Tr	Tr	24	20	20	-	-	30	-	-	10	12
Plagioclase (% An)	10(32)	10(42)	24(40)	34(45)	25(20)	30(30)	30(14)	13(38)	34(45)	20(10)	14(40)	13(44)	32(30)	30(40)
K-Feldspar	13	8	5	Tr	5	5	-	-	-	-	-	-	-	-
Quartz	7	5	3	2	-	-	-	10	4	-	10	7	-	-
Calcite	-	12	1	5	-	-	5	Tr	-	2	-	-	Tr	4
Olivine "morphs" (chlorite)	2	Tr	7	Tr	14	Tr	2	-	-	2	-	-	4	5
Pyroxene	10	20	17	18	-	-	-	-	-	-	-	-	-	-
Amphibole	13	5	-	-	-	-	-	55	50	-	60	56	-	-
Biotite	5	Tr	Tr	Tr	-	-	-	1	10	-	Tr	2	-	-
Chlorite	5	10	13	17	5	10	10	2	-	14	Tr	-	14	15
Saussurite (sericite)	20	14	16	16	8	5	10	18	-	16	15	20	10	5
Ilmenite-Iron oxide	13	15	13	8	9	10	5	1	1	6	1	1	5	9
Sphene	Tr	1	1	Tr	Tr	Tr	Tr	Tr	1	Tr	Tr	1	Tr	Tr
Apatite	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Pyrite, pyrrhotite	2	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Groundmass	-	-	-	-	10	20	18	-	-	10	-	-	25	20

CHAPTER V - CHEMICAL COMPOSITION

INTRODUCTION

A chemical study of the Purcell igneous rocks seemed justified for a number of reasons:

(1) Few chemical analyses were done on the basic igneous rocks in the thesis area (Daly, 1912; Schofield, 1915; Jure, 1929). One complete chemical analysis of the Purcell lava was available (Daly, 1912, p. 209). Field work and thin section studies indicated there may be more than one basic Precambrian igneous province. Chemical analyses from the western and eastern Purcell igneous rocks would be useful for comparative purposes.

(2) The Purcell lava formation appeared to be universally composed of highly altered plagioclase feldspar, chlorite and iron oxides. Original constituents which were replaced mainly by chlorite were difficult to identify in thin section. The flows were classified as andesites, or altered basalts. Molecular norms would serve as a useful correlation "tool" and perhaps help to deduce the original constituents of the rocks.

COLLECTION AND PREPARATION

The writer collected and prepared about twenty samples for chemical analysis. However, the Rock Analysis Laboratory of the University of Alberta could complete only five of the twenty prepared samples because of other commitments. The locations of the samples are given in Table 3. The samples were selected to give a wide geographic coverage of the Purcell igneous rocks. It was thought that samples from the basal portions, near the chilled margins of the lavas would give the best representative analysis

TABLE 3. COMPOSITION OF PURCELL IGNEOUS ROCKS

A. WEIGHT PERCENTAGES OF OXIDES

	1	2	3	4	5	6	7	8	9
SiO_2	41.50	51.92	50.36	52.94	44.85	50.81	46.14	48.06	47.55
TiO_2	3.33	0.83	0.90	0.73	2.66	0.90	3.63	2.20	4.00
Al_2O_3	17.09	14.13	13.63	14.22	14.69	13.82	15.36	15.29	16.72
Fe_2O_3	3.31	2.97	2.22	2.08	0.85	0.73	4.08	1.37	1.93
FeO	10.08	6.92	8.38	8.11	9.34	11.02	10.69	11.82	7.76
MnO	-	0.14	0.20	0.35	0.10	0.20	0.22	0.19	0.08
MgO	12.74	8.22	8.67	6.99	8.50	8.11	4.26	4.71	6.24
CaO	0.97	11.53	11.50	10.92	5.08	9.38	6.89	6.56	0.95
Na_2O	2.84	1.38	2.54	1.40	2.32	1.67	3.06	3.00	0.26
K_2O	0.22	0.47	0.75	0.49	1.76	0.63	1.86	1.66	9.47
P_2O_5	1.08	0.04	0.07	0.08	0.05	0.16	0.70	0.54	0.74
H_2O^-	0.21	0.10	0.71	0.12	0.06	0.05	0.25	0.14	0.25
H_2O^+	6.99	1.07	0.05	1.56	5.54	2.44	2.24	3.33	4.21
CO_2	-	0.06	-	-	3.56	0.15	0.33	0.85	0.02
S	-	-	-	-	.01	-	0.10	0.17	-
LESS O=S							0.05	0.09	
TOTAL	100.36	99.78	99.98	99.99	99.81	100.07	99.76	99.80	100.18

Explanation of Table 3

1. Lava, Yahk River, British Columbia, porphyritic amygdaloid, 250 feet above lower contact (R.A. Daly, 1912, p. 209). No published mode available.

2. Sill, Moyie River, British Columbia. Hornblende gabbro (R.A. Daly, 1912, p. 224).

3. Sill, St. Mary Lake, British Columbia. Pyroxene gabbro (S.J. Schofield, 1915, p. 58). No published mode available.

4. Sill, Kingsgate, British Columbia. Hornblende gabbro, 30 feet above lower contact (R.A. Daly, 1912, p. 234).

5. Lava, Lussier River, British Columbia. Amygdaloidal basalt, 50 feet above lower contact (A. Stelmach, Univ. of Alta., 1961, Sample No. LR-18).

6. Sill, Irishman Creek, British Columbia. Quartz diabase, 5 feet above lower contact (A. Stelmach, Univ. of Alta., 1961, Sample No. IR-5).

7. Lava, Blakiston Brook, Alberta. Pyroxene diabase, near upper contact (A. Stelmach, Univ. of Alta., 1961, Sample No. BB-4).

8. Lava, Ruby Ridge, Alberta. Pyroxene diabase, 3 feet above lower contact, (A. Stelmach, Univ. of Alta., 1961, Sample No. RR-3).

9. Lava, Mt. Rowe, Alberta. Amygdaloidal basalt, near lower contact, (A. Stelmach, Univ. of Alta., 1961, Sample No. CC-37).

TABLE 3. Continued

B. MOLECULAR NORMS (Calculated after Barth, 1952)

	1	2	3	4	5	6	7	8	9
Q ------------	0.3	6.9	-	8.0	-	2.5	-	-	-
C ------------	14.0	-	-	-	1.7	-	-	-	7.1
Or -----------	1.5	3.0	4.5	3.0	13.0	4.0	12.0	10.0	59.5
Ab -----------	27.0	12.5	23.0	13.0	22.5	15.5	30.0	28.5	2.0
An -----------	-	32.0	24.0	32.5	22.0	29.0	25.0	24.5	-
Ol -----------	-	-	9.9	-	9.0	-	13.2	-	6.0
Wo -----------	-	10.6	13.6	9.6	-	7.0	3.4	0.2	-
En -----------	37.6	23.4	15.4	20.4	17.4	23.4	2.9	13.8	12.3
Fs -----------	9.2	6.8	6.6	10.8	7.4	15.8	2.1	14.6	3.7
Mt -----------	3.6	3.6	1.8	1.8	0.9	0.8	4.6	1.5	2.1
Il -----------	5.0	1.2	1.2	1.0	4.2	1.2	5.4	3.2	5.8
Ap -----------	1.9	-	-	-	1.1	0.3	1.3	1.1	1.6
Cc -----------	-	-	-	-	0.8	0.4	-	2.2	-
Pr -----------	-	-	-	-	-	-	-	0.5	-
Calculated %An	0	72	51	72	48	65	45	46	0

C. MODES

Plagioclase --		34.8		25.6	40	30	56	25	20
% An ---------		50-70		50-70	32	50-70	27-70	70	10
Quartz -------		4.0		6.3	-	5	-	Tr	-
Olivine "morphs" (Chlorite)		-		-	5	-	10	-	5
Pyroxene -----		-		-	-	-	17	20	-
Amphibole ----		58.7		54.8	-	55	-	-	-
Biotite ------		0.9		-	-	-	2	-	-
Chlorite -----		-		11.0	25	3	5	20	10
Ilmenite-Magnetite ---		0.7		0.3	8	1	10	13	10
Sphene -------		0.7		0.2	-	1	Tr	Tr	-
Apatite ------		0.2		-	-	Tr	Tr	Tr	-
Epidote,sericite zoisite,kaolin-ite ---------		-		-	-	5	-	20	-
K-feldspar ---		-		-	-	-	-	-	30
Calcite ------		-		-	5	-	-	2	-
Pyrite, pyrrho-tite --------		-		-	-	-	-	Tr	-
Amygdules(chlor-ite,quartz)--		-		-	17	-	-	Tr	5
Groundmass ---		-		-	-	-	-	-	20

of the chemical character of the rock. A sample was selected from the upper contact of the Blakiston Brook flow to determine whether the chemical analysis would indicate any marked iron-enrichment towards the top of the lava.

All samples for chemical analyses were prepared from large, representative hand specimens. They were crushed to "pea-size" material by means of a small jaw crusher. The crushed rock was reduced in size with the use of a Platner mortar and pestle to pass through an 80 mesh screen. Numerous quarter samples were taken until a sample of about 20 grams was obtained. The quarter samples were bottled and sent to the Rock Analysis Laboratory of the University of Alberta.

RESULTS

The results of five complete chemical analyses, done by A. Stelmach of the University of Alberta, are shown in Table 3, part A, analyses 5 to 9. The analyses 1 to 4, obtained from Geological Survey of Canada publications (R.A. Daly, 1912; S.J. Schofield, 1915) are plotted in Table 3 for comparative purposes.

INTERPRETATION AND COMPARISON

Definitions

1. Basalts -- Turner and Verhoogen (1960, p. 71) defined the basalt family as basic volcanic rocks with calcic plagioclase, augite, and in many cases, olivine as essential constituents. In their outline

of the basalt family, they listed four classes of basalts for the purposes of petrogenic discussion.

Olivine basalt -- contains olivine.

Tholeiitic basalt -- poor or lacking olivine.

Trachybasalt -- olivine basalt with high Na_2O or K_2O content. Mugearite is an allied type with oligoclase-andesine feldspar, augite, and olivine.

Spilite -- highly sodic, olivine-poor basalt with albite or oligoclase the sole or principal feldspar.

An olivine basalt is characterized by pyroxene of diopsidic or basaltic augite type, often a titaniferous variety; essential olivine; and possibly some interstitial material of alkaline nature with no free quartz (Kennedy, 1933, p. 241).

2. Andesites -- Andesites are rocks consisting of andesine or labradorite and some combination of augite, hypersthene, and hornblende. Type transitional to basalt may carry olivine (Turner, 1951, p. 63).

Andesites are separated from basalts solely on criterion of the kind of plagioclase; if less than An_{50} the rock is andesite, if more calcic, the rock is basalt (Hatch, 1949, p. 305).

W.W. Moorhouse (1959, p. 188) stated, "A further misuse of the term andesite is the application of it to altered basalts, such as the greenstones of the Keewatin. The usage probably stems for the sodic feldspar they contain and their lighter colour, due to chloritization and carbonatization of the ferromagnesian. It should be avoided."

3. Tholeiitic basalt vs. olivine basalt -- W.Q. Kennedy (1933) has distinguished between two types of flood basalt magma; the tholeiitic

basalt with its quartz diabase association and the alkaline olivine basalt with related gabbro.

Turner and Verhoogen (1960, p. 206) gave the following criteria for the petrographic and chemical distinctions between tholeiitic and alkaline olivine basalts.

In tholeiitic basalts, olivine is magnesian and unzoned; two pyroxenes are commonly associated, viz., augite with pigeonite or with hypersthene or even with subcalcic augite (in a chilled groundmass); pyroxenes of late differentiates are enriched in iron.

In alkaline olivine basalts, the olivine is strongly zoned but the pyroxene is uniform in composition--a titan-augite closely approximating the diopside-salite series and seldom richer in ferrous ions than Ca_{45} Mg_{25} Fe_{30}.

In both classes of basalt the residuum is commonly partly or completely replaced by the ferruginous mineraloid chlorophaeite or is charged with opaque black particles.

Chemically, the percentage of SiO_2 is higher, the percentages of Na_2O, K_2O and MgO are lower, and the MgO/CaO ratio is lower in tholeiitic basalts than in most alkaline olivine basalts.

4. Petrographical province -- J.W. Judd (1886) proposed, "There are distinct petrographical provinces within which the rocks erupted during any particular geological period present certain well-marked peculiarities in mineralogical composition and microscopical structure, serving at once to distinguish them from the rocks belonging to the same general group, which were simultaneously erupted in other petrographical provinces."

Discussion

The Purcell igneous rocks found in the western part of the thesis area can be compared to those in the eastern part.

Petrographically, the Purcell lava formation in the Siyeh sediments belongs to the basalt family on the basis of the An content of the plagioclase feldspars and the presence of olivine and pyroxene relict grains. In the east, titaniferous augite, olivine pseudomorphs and calcic plagioclase are the main constituents of the thin local flows found mainly below the Siyeh sediments. In the west no fresh pyroxene-bearing lavas have been reported. A thin, local rhyolite flow was described in the Purcell Range by Daly.

The mineralogy of the western Purcell intrusive rocks differs markedly from the eastern intrusions. Most of the intrusions in the west are diorites, except for the pyroxene gabbro in the St. Mary Lake area (Schofield, 1914). In the east the intrusions are classified as pyroxene-bearing gabbro.

The Purcell extrusive rocks, on the basis of the chemical compositions plotted in Table 3, are members of the basalt family. Probably, the best chemical criterion for a basalt is the universal low percentage of SiO_2. The Purcell extrusions have an SiO_2 range from 41.5 to 48.06 per cent. In Table 4, the average SiO_2 per cent for 49 andesites used by Poldervaart (1954) is about 5 per cent higher than the Purcell extrusions. Barth (1952, p. 69) listed values of 49.06 per cent SiO_2 for an effusive basalt and 59.59 per cent SiO_2 for an effusive andesite in a table of average chemical compositions. It is noted that the SiO_2 content is higher (3 per cent) in the eastern Purcell extrusive rocks than in the west.

There may be two "anomalous" results recorded in Table 3. Analysis

TABLE 4. COMPARISON OF COMPOSITIONS

	1	2	3	4	5	6	7	8	9
SiO_2	46.5	49.0	51.9	54.6	49.70	49.0	48.35	51.8	51.22
TiO_2	3.2	3.4	0.8	1.3	2.23	2.2	2.77	2.4	3.32
Al_2O_3	16.9	16.5	14.2	17.4	14.24	16.3	13.18	14.0	13.66
Fe_2O_3	2.2	2.6	2.0	3.5	3.66	3.5	2.35	3.9	2.84
FeO	10.1	10.5	8.7	5.5	9.96	10.0	9.08	8.7	9.20
MnO	0.1	0.2	0.2	0.2	0.17	0.2	0.14	0.2	0.25
MgO	11.3	5.2	8.0	4.4	6.82	3.2	9.72	5.6	4.55
CaO	3.4	4.9	10.9	8.0	9.55	6.6	10.34	9.2	6.89
Na_2O	2.7	2.1	1.8	3.7	2.64	5.2	2.42	2.4	4.93
K_2O	0.9	4.4	0.5	1.1	0.70	2.1	0.58	0.9	0.75
P_2O_5	0.7	0.6	0.8	0.3	0.33	1.5	0.34	0.3	0.29
Co_2	1.9	0.4	0.1	-	-	0.1	-	0.6	-

Explanation of Table 4

Note: All compositions are calculated water-free

1. Average of analyses 1 and 5 from Table 3, "western" Purcell lava.

2. Average of analyses 7 to 9 from Table 3, "eastern" Purcell extrusive rocks.

3. Average of analyses 2, 3, 4, and 6 from Table 3, "western" Purcell diabase sills.

4. Average of forty-nine andesites used by Poldervaart (1954, pp. 133-141), Chemistry of the Earth's Crust, G.S.A. Special Paper 62.

5. Average of forty-three tholeiitic basalts used by Wells (1949), The Petrology of Igneous Rocks.

6. Analysis of mugearite used by Turner and Verhoogen (1960, p. 168), Igneous and Metamorphic Petrology.

7. Average of olivine basalt, Hawaiian Archipelago (G.A. Macdonald, Hawaiian petrographic province, Bull. G.S.A., vol. 60, 1949).

8. Average of six analyses from the Whin sill used by Turner and Verhoogen (1960, p. 215).

9. Average spilite (N. Sundius, Geol. Mag., vol. 67, p. 9, 1930).

No. 9 shows the percentages 9.47 for K_2O and 0.95 for CaO of the Mt. Rowe lava, markedly different when compared with other Purcell percentages. Although, a similar percentage value, 0.97 for CaO of the Yahk River lava is given in analysis No. 1 of Table 3, an explanation of these "anomalous" results is difficult. The Siyeh argillites, which underlie the Mt. Rowe lavas, contain K-feldspars and sericite which could act as potash contamination. Some of the "balled-up" sedimentary accumulations, incorporated in the base of the flow, may have enriched the K_2O content of the lava. C.P. Ross (1959, p. 55) gave chemical analyses of the Proterozoic formations with K_2O ranges from 2.90 to 5.27 per cent for the argillites in Glacier National Park, immediately to the south of Mt. Rowe. Since the eastern intrusive rocks contain important amounts of orthoclase and biotite, it might be argued that assimilation played an important role in the crystallization of the potash-rich eastern intrusions. However, most of these intrusions are confined to the potash-poor Siyeh limestone (Ross, 1959).

In Table 4, column No. 1, the averages of the western lava compositions show a low SiO_2 value, high MgO/CaO ratio which may be of the olivine basalt type and comparable to the average olivine basalt plotted in analysis No. 7. The chemical averages of the eastern Purcell extrusive rocks, Table 4, column No. 2, may be comparable to the alkaline olivine basalt as plotted in column 6 of Table 4.

Normative olivine is present in some of the Purcell extrusive and intrusive phases from the eastern and the western parts of the thesis area.

Perhaps the most striking character of the tholeiitic flood basalts is the occurrence of their intrusive quartz diabase equivalents. Both chemically and petrographically the diabases have been investigated in

much greater detail than the tholeiitic basalts. Well documented diabases include the Whin sill, the Hangnest sill and other Karoo diabases, the Palisade sill, and the sills and dykes of Tasmania. The chemical compositions of these diabases are almost identical to those sills of the western Purcell terrain (Turner and Verhoogen, 1960, p. 215). In Table 4, the average of the western Purcell sills (3) is compared to the average of six analyses from the Whin Sill (8) given by Turner and Verhoogen (1960). The western Purcell sills and the Whin sill both have SiO_2 contents near 50 per cent.

The western Purcell sills are mainly composed of amphibole (over 50 per cent). Many of the previous workers on the Purcell sills (Calkins, 1909; Schofield, 1915; Anderson, 1930; Gibson and Jenks, 1938; Rice, 1941) considered the amphibole to be a secondary hornblende and an alteration product of pyroxene. R.A. Daly (1912) concluded that the fibrous amphibole is secondary after the compact form. Barth (1952) in discussing evidence of assimilation by diabases, stated, "A prerequisite seems to be a high water content. In such magmas the temperature of crystallization is depressed, and hornblende crystallizes instead of pyroxene, producing hornblende-biotite diabases that are mineralogically different from, but chemically similar to, the ordinary pyroxene diabases".

If the St. Mary Lake sill was emplaced contemporaneously with the Purcell lava in the Cranbrook area, the sill would have intruded Aldridge sediments about 26,000 feet stratigraphically below its extrusive equivalent in the Siyeh formation. Mason (1956, p. 100) considered the problem of whether an amphibole or a pyroxene or both would crystallize

from a magma. He stated, "Amphiboles occur more often in plutonic rocks than in volcanic rocks, evidently because the incorporation of OH groups in the structure is favored by crystallization under pressure. However, the composition of the magma may also be significant. The Ca:Fe:Mg ratios of igneous hornblendes and pyroxenes show characteristic differences: the hornblendes fall in the composition gap between augite and the pigeonites and orthorhombic pyroxenes."

If the amphibole of the western Purcell sills is secondary after pyroxene, why is there such meagre evidence of this transformation? Although Reesor (1958, p. 30) stated that in the Dewar Creek area, ".... the sills were composed of diorite in which most of the original pyroxene has been replaced by amphibole", no pyroxene or pyroxene relicts were recognized by the writer in the western Purcell sills. Petrographic evidence suggests a primary-deuteric interpretation for the origin of the green and fibrous amphibole in the western Purcell sills.

In Figure 20, the MgO-FeO-alkalies diagram depicts a highly speculative interpretation of the trend of change for the analysed Purcell igneous rocks. Since there are so few analyses, it is difficult to formulate a probable genetic relation between the eastern and western Purcell rocks. However, the trend (see arrow on Figure 20) may indicate one of the following petrogenetic relationships:

1. Varying stages of differentiation from a common regional basaltic source.

2. Variation due to assimilation of older rocks and/or post-magmatic alteration.

3. Different basaltic sources.

FIGURE 20

MG O - FE O - ALKALIES DIAGRAMS FOR PURCELL ANALYSED ROCKS

DIFFERENTIATION INDEX

Introduction

C.P. Thornton and O.F. Tuttle (1960) give a method whereby any chemical analysis of an igneous rock can be compared at a glance with the 5000 superior analyses in Washington's Tables. As a means of comparison they plot a series of diagrams in which the abscissa is called the differentiation index or D.I., based on Bowen's work. Bowen (1937) proposed that fractional crystallization of complex magmas produces liquids which move toward, and for all practical purposes eventually reach, the system SiO_2-$NaAlSiO_4$-$KAlSiO_4$, petrogeny's residua system. The quantitative measurement of this residua system or the differentiation index is the sum of the weight percentages of normative quartz + orthoclase + albite + nepheline + leucite + kalsilite. As there are never more than three of these normative minerals in any given norm, the D.I. is the sum of the percentages of three normative minerals. Thornton and Tuttle's frequency distribution diagrams with the differentiation index plotted against the oxide percentage were contoured by the usual petrofabric technique with the counting area being 0.16 per cent instead of the usual one per cent area. In all the diagrams, with the exception of silica, the area between the outermost and the next higher contour contains from 1 to 25 points in a 0.16 per cent area, the next area contains 26-50 points, the next 51 to 75, then 76 to 100, 101 to 125, 126 to 150, 151 to 175, etc. In the silica diagram two extra contours are included because of the greater spread in SiO_2 values. These contours represent 1 to 12, 13 to 25, 26 to 38 and 39 to 50 points in a 0.16 per cent area.

[illegible]

[illegible]

[illegible]

Comparison

In Figure 21, the nine Purcell rock analyses, numbers 1 to 9 from Table 3, are changed to numbers 20 to 28 and are plotted on Thornton and Tuttle's contoured frequency distribution diagrams for the 5000 superior analyses in Washington's Tables. The differentiation index for eight of the Purcell igneous rocks ranges from 22 to 42 and compares favourably with the olivine diabase, D.I. = 30 and the basalt, D.I. = 35, given by Thornton and Tuttle (p. 671).

Silica distribution.--The maximum concentration of Purcell analyses, numbers 20 to 27, of Figure 21A, falls in an area at D.I. = 22 to 42 and a silica content of about 50. This area corresponds to the gabbro and basalt maxima of Washington's analyses with a D.I. of 38 and a silica content of about 52. Analysis no 28 appears to be anomalous.

Alumina distribution.--The distribution of the Purcell alumina content is shown in Figure 21B. Analyses 20 and 28 represent the highest alumina values for the Purcells.

Ferric and Ferrous distributions.--Ferric oxide distribution in Figure 21C of the Purcell rocks has a range of values which parallels the main trend for the Washington analyses. Ferrous oxide analyses 25 to 28 in Figure 21D appear to be anomalous and have high percentage values.

Magnesia, lime and alkali distributions.--Magnesia analyses 20 and 28 in Figure 21E fall higher on the diagram than the main trend for the Washington analyses. Lime analyses 20 and 28 in Figure 21F are anomalously low when compared with the main frequency distribution trend. Alkali distribution diagrams, Figure 21G and 21H, show that the Purcell

analysis 28 is not in harmony with the main trends of the soda and potash diagrams.

Thornton and Tuttle (1960, p. 674) stated, "The silica D.I. diagram is a useful means of distinguishing undersaturated from over-saturated rocks. If a line is drawn from the silica content of albite at D.I. = 100 (68.7 per cent silica) to the silica content of anorthite at D.I. = 0 (43.2 per cent silica), those analyses falling below the line are largely undersaturated whereas those above the line are over-saturated." Thornton and Tuttle used the word undersaturated with reference to an igneous rock which had a relatively low silica content and the word oversaturated was used for a rock with a relatively high silica content compared with other rocks of the same differentiation index. In Figure 21i, some extrusive rock analyses, numbers 1 to 19, or S.R. Nockolds (1954) are plotted along with the nine Purcell analysed rocks from Table 3 (re-numbered 20 to 28). Nockolds' rock types are as follows: 1. calc-alkali rhyolite; 2. alkali rhyolite; 3. calc-alkali trachyte; 4. alkali trachyte; 5. phonolite; 6. dellenite; 7. rhyodacite; 8. latite; 9. doreite; 10. alkali doreite; 11. ordanchite; 12. dacite; 13. andesite; 14. alkali andesite; 15. tephrite; 16. tholeiitic basalt; 17. tholeiitic olivine basalt; 18. alkali basalt; 19. nephelinite.

It is noted that the four Purcell analysed sills, numbers 21, 22, 23, and 25, fall near Nockolds' tholeiitic basalt analysis no. 16 (Figure 21i). The Purcell extrusive rock analyses 20, 24, 26, 27 and 28 fall in the undersaturated area.

[illegible]

[illegible]

[illegible]

Conclusions

Variation diagrams in Figure 21 indicate two separate areas of analyses, with one area at D.I. = 22 to 36 representing the western Purcell igneous rocks and the other area at D.I. = 39 to 62 representing the eastern Purcell rocks. Analysis 28, D.I. = 62 appears to be from a very unusual igneous rock when compared to the average for 5000 analyses in Washington's Tables.

The differentiation index, which is a measure of the amount of salic and femic constituents in the norm, can be used to classify the Purcell igneous rocks. The D.I. for the Purcell analysed rocks is closely comparable to that of Daly's average basalt, D.I. = 35 and olivine basalt, D.I. = 30.

The western Purcell intrusions, analyses 21, 22, 23, and 25, have a range of D.I. values similar to the western Purcell extrusions, analyses 20 and 24 in Figure 21. It is noted, however, that the intrusive rocks in the western area are oversaturated, while the extrusive rocks are under-saturated (Figure 21i). The intrusive rocks fall very close to the position of Nockolds' tholeiitic basalt (16) on the SiO_2-D.I. diagram. The Irishman Creek sill, analysis 25 has the lowest D.I. value of the Purcell rocks. If variations within the Purcell igneous rocks are related to processes involving magmatic evolution, the low differentiation index may suggest that this sill was emplaced earlier than the other sills for which analyses are available.

If the eastern and western Purcell igneous rocks were derived from the same magmatic source, the differentiation trend for each oxide should closely parallel the main trend in each of Thornton and Tuttle's diagrams.

[illegible]

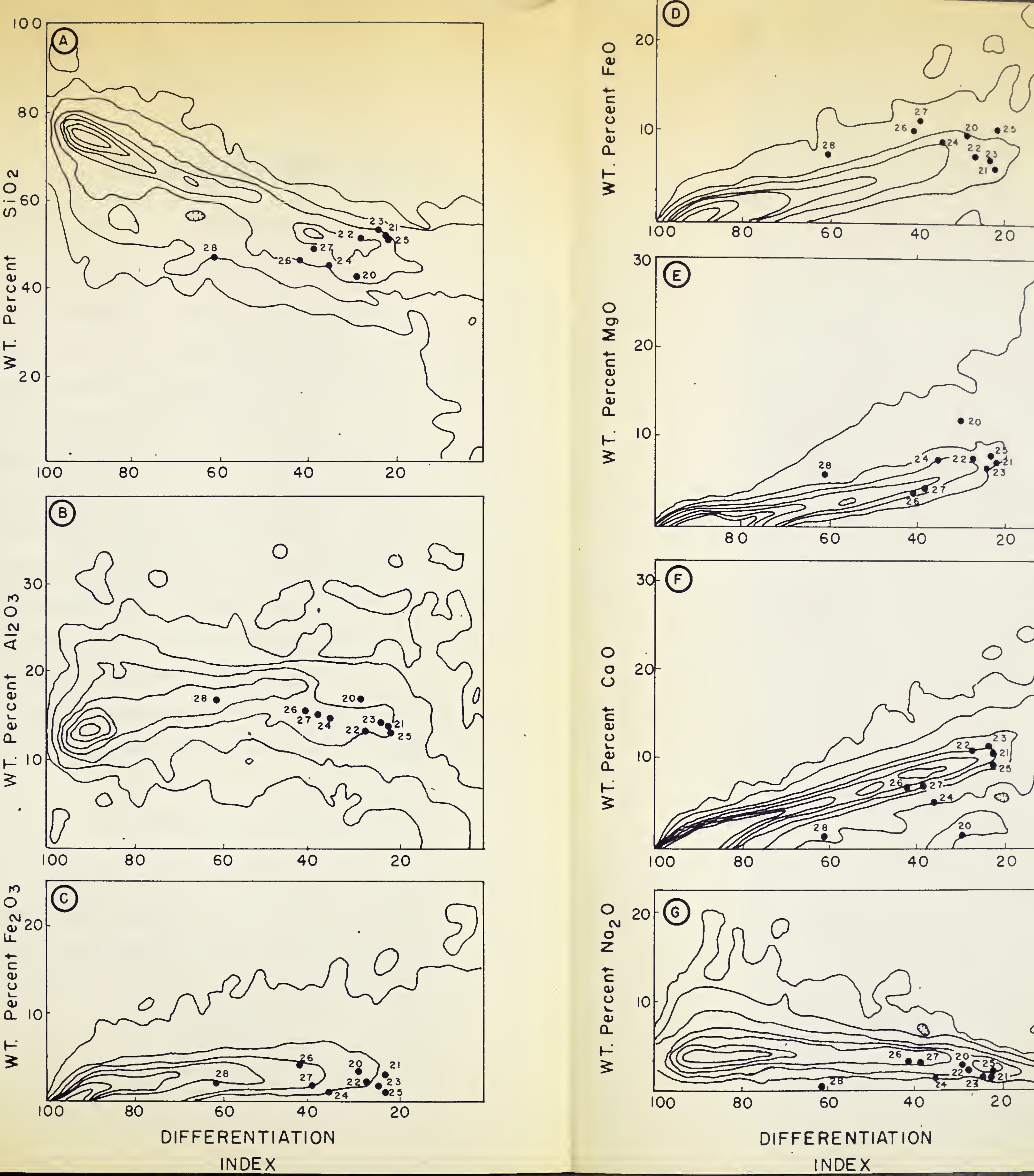
[illegible]

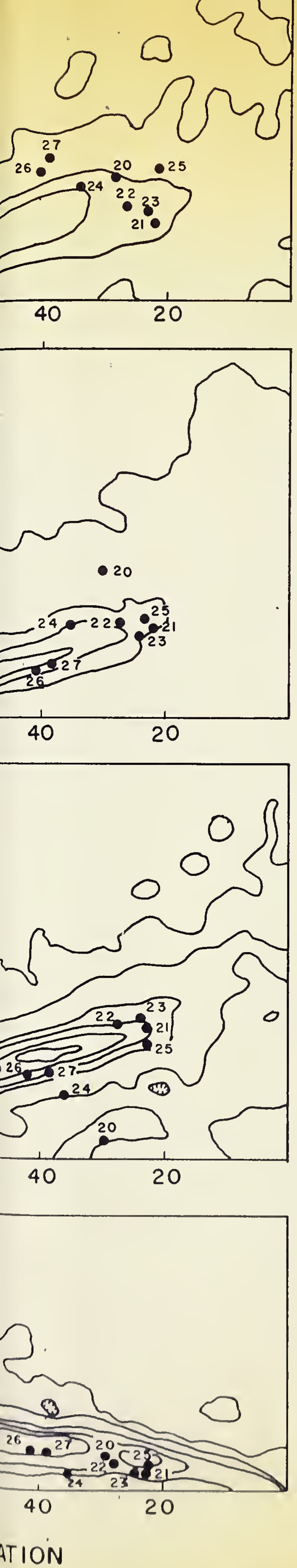
[illegible]

[illegible]

[illegible]

This parallelism has been demonstrated for rock series such as those from the Highwood and Katmai petrologic provinces. The nine randomly selected samples of the Purcell rocks from a wide geographic area do not fully conform to the highest contours on the differentiation trends, but the departures are not marked, with the exception of analysis 28. The fact that the eastern Purcell igneous rocks have relatively higher D.I. values and are more alkaline in composition than the western rocks suggests the possibility of two magmatic sources. More chemical analyses would be required to establish the petrogenetic relation between the eastern and western Purcell areas.


A
WT. Percent SiO2
B
WT. Percent Al2O3
C
WT. Percent Fe2O3
D
WT. Percent FeO
E
WT. Percent MgO
F
WT. Percent CaO
G
WT. Percent Na2O
20
21
22
23
24
25
26
27
28
100
80
60
40
20
DIFFERENTIATION
INDEX
DIFFERENTIATION
INDEX



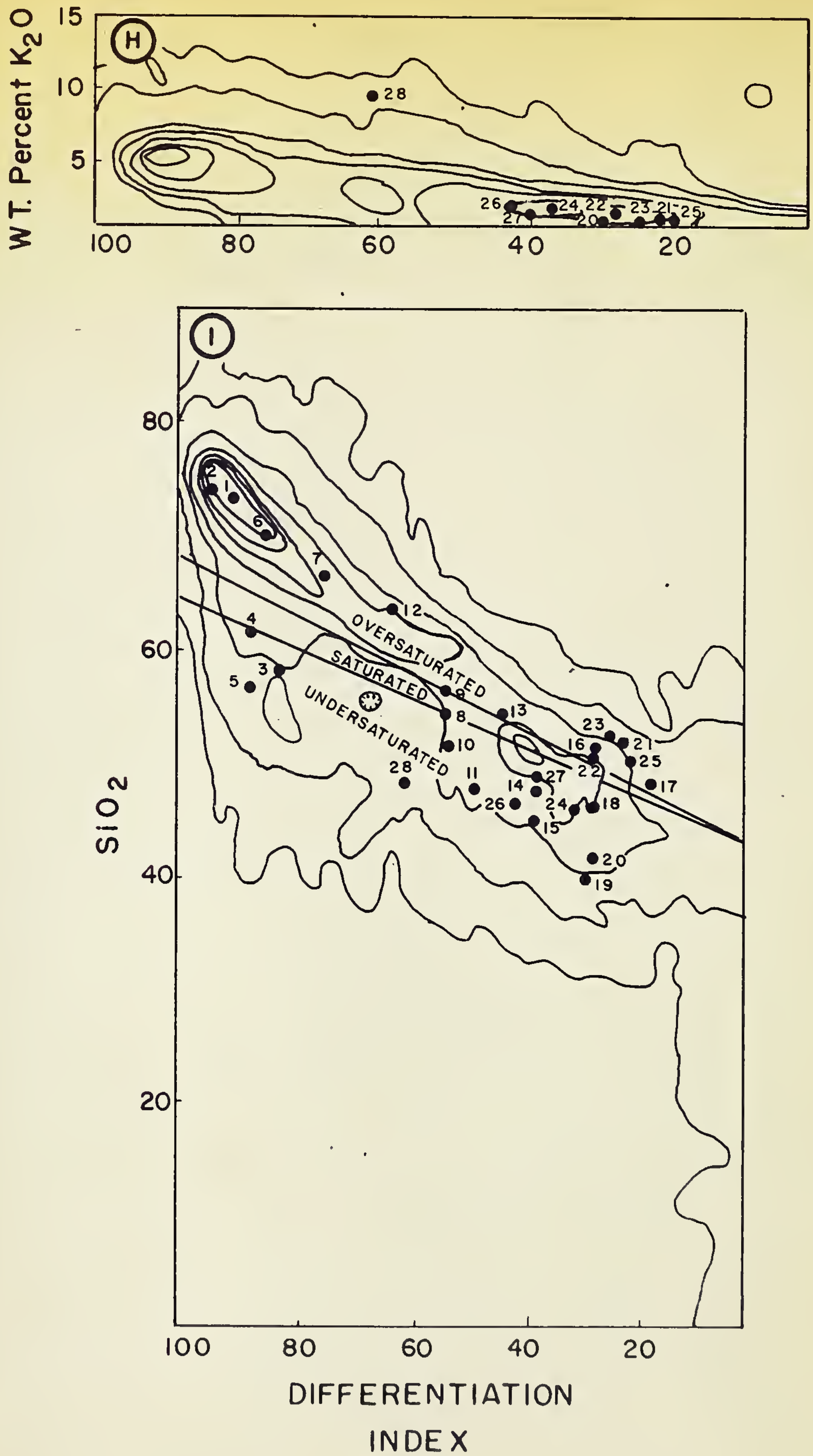


FIGURE 21. Variation Diagrams for Purcell Rocks.

CHAPTER VI - PHYSICAL AGE DETERMINATIONS

INTRODUCTION

K-Ar dating was undertaken:

(1) To establish the time of intrusion and extrusion of the basic igneous rocks in the thesis area. Since the sills are found entirely within Precambrian sediments, it is not possible to determine age relations by paleontologic evidence.

(2) To check the use of amphibole for potassium-argon dating, since little information on amphibole dating techniques and interpretations are available at the present time (Hart, S.R., et al, 1960).

(3) To evaluate the effect of younger granitic intrusions on the age determinations made on minerals from the sills. A number of granites were dated in the hope of determining the sequence of events of the acid intrusive complex in the area.

(4) To compare and correlate the time relationships of the Purcell igneous rocks found in the Purcell terrain and in adjacent areas to the south.

COLLECTION AND PREPARATION OF SAMPLES

The writer used considerable care to obtain the freshest or least-weathered hand specimen in the field for K-Ar dating. The desired minerals were then extracted from the hand specimen as shown schematically in Figure 22.

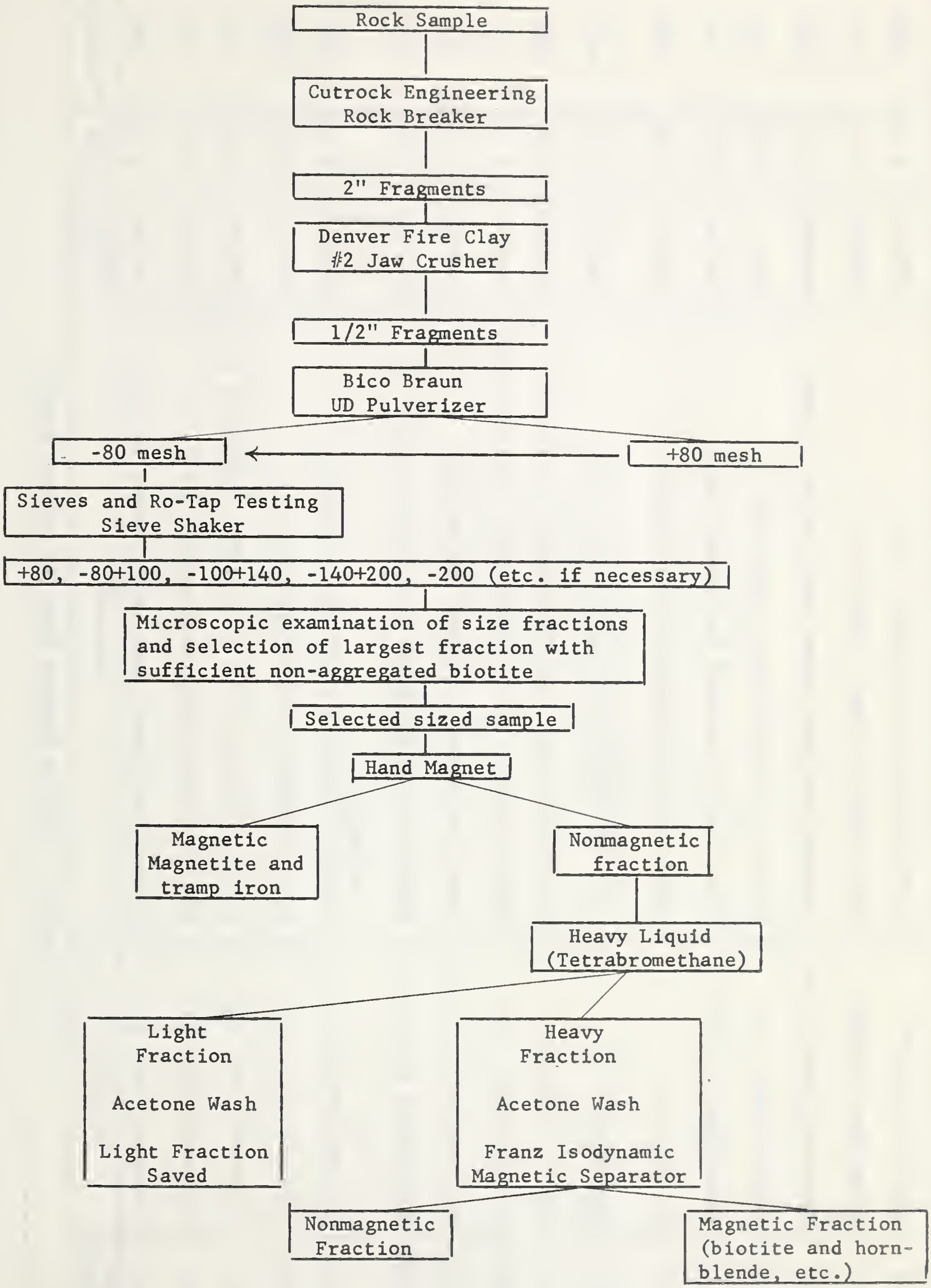


Figure 22. Separation of age date minerals

TABLE 5. DATA ON SAMPLES DATED IN PRESENT STUDY

K-Ar No.	Sample No.	Locality	Occurrence	Dated Mineral	$\%K_2O$	Age(10^6yrs)
66	IR-10	Irishman Creek, B.C.	Biotite vein found above upper contact of sill	Biotite	9.73	669
70	IR-4	Irishman Creek, B.C.	Biotite found within lower margin of sill	Biotite	3.06	835
154	IR-3	Irishman Creek, B.C.	Biotite hornfels found below lower contact of sill	Biotite	7.26	844
161	IR-25	Irishman Creek, B.C.	Green amphibole found within the sill	Amphibole	0.30	1580
73	HR-30	Hellroaring Creek, B.C.	Hornfels developed below lower contact of pegmatite	Biotite	6.78	283
72	HR-33A	Hellroaring Creek, B.C.	Hornfels developed below contact of a sill	Biotite	8.54	183
152	HR-36	Hellroaring Creek, B.C.	Muscovite-granite intruding diabase sill	Muscovite	10.44	769
158	SM-10	St. Mary Lake, B.C.	Green amphibole found within the St. Mary "A" sill	Amphibole	0.51	766
159	DP-13	Dipper Lake, B.C.	Coarse green amphibole found within a thick sill	Amphibole	0.40	883
160	EK-1	Kimberley, B.C.	Green amphibole found within a sill near Sullivan Mine	Amphibole	0.15	1073
153	EK-2	Wycliffe, B.C.	Granite stock intruding Cambrian sediments	Biotite	7.07	102
65	SC-25	Skookumchuck Creek,B.C.	Minette dyke intruding the Purcell lava	Biotite	9.42	104
142	LR-17	Lussier River, B.C.	Purcell lava found near a fault zone	Lava	3.00	107
155	W-16	Blakiston Brook, Alta.	Hornfels developed below lower contact of lava	Hornfels	2.10	1075
162	LP-4	Logan Pass, Montana	Brown amphibole found within a sill	Amphibole	0.48	1110
157	PM-1	Paradise, Montana	Green amphibole found within a sill	Amphibole	0.30	1400

If the sample contains both hornblende and biotite in the final magnetic separate, two other techniques of separation may be used. They are based on the fact that the biotite has a good basal cleavage and the amphibole is prismatic in outline.

(1) Rolling Method - the sample is passed over a series of paper sheets, allowing the biotite flakes to adhere to the paper and the amphiboles to roll off.

(2) Crushing Method - the sample is placed on a stainless steel plate and crushed with a small steel rolling pin. Upon resieving, the crushed hornblende will pass through the screen and much of the uncrushed flat-lying biotite remains intact on top of the screen.

RESULTS

All the K-Ar samples were processed by H. Baadsgaard at the University of Alberta. The potassium-argon age determinations, calculated by the writer, are shown in Table 5.

The analytical error for the individual determinations is considered to be $\pm$ 6 per cent. The determinations have been based on the following constants:

$$\lambda_e = 0.589 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_\beta = 4.76 \times 10^{-10} \text{ yr}^{-1}$$

$$K^{40}/K = 0.000118 \text{ atomic per cent abundance}$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

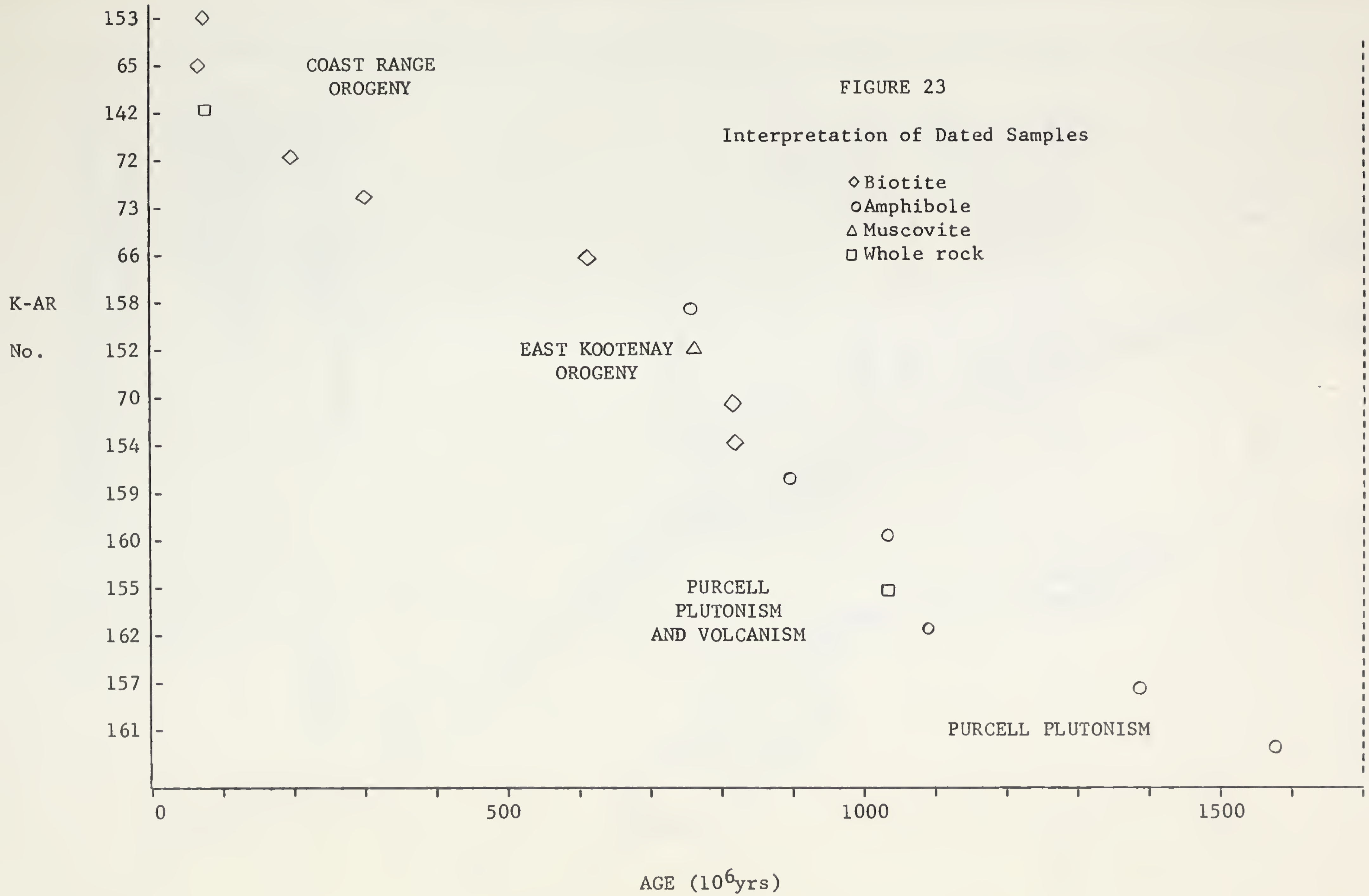


FIGURE 23

Interpretation of Dated Samples

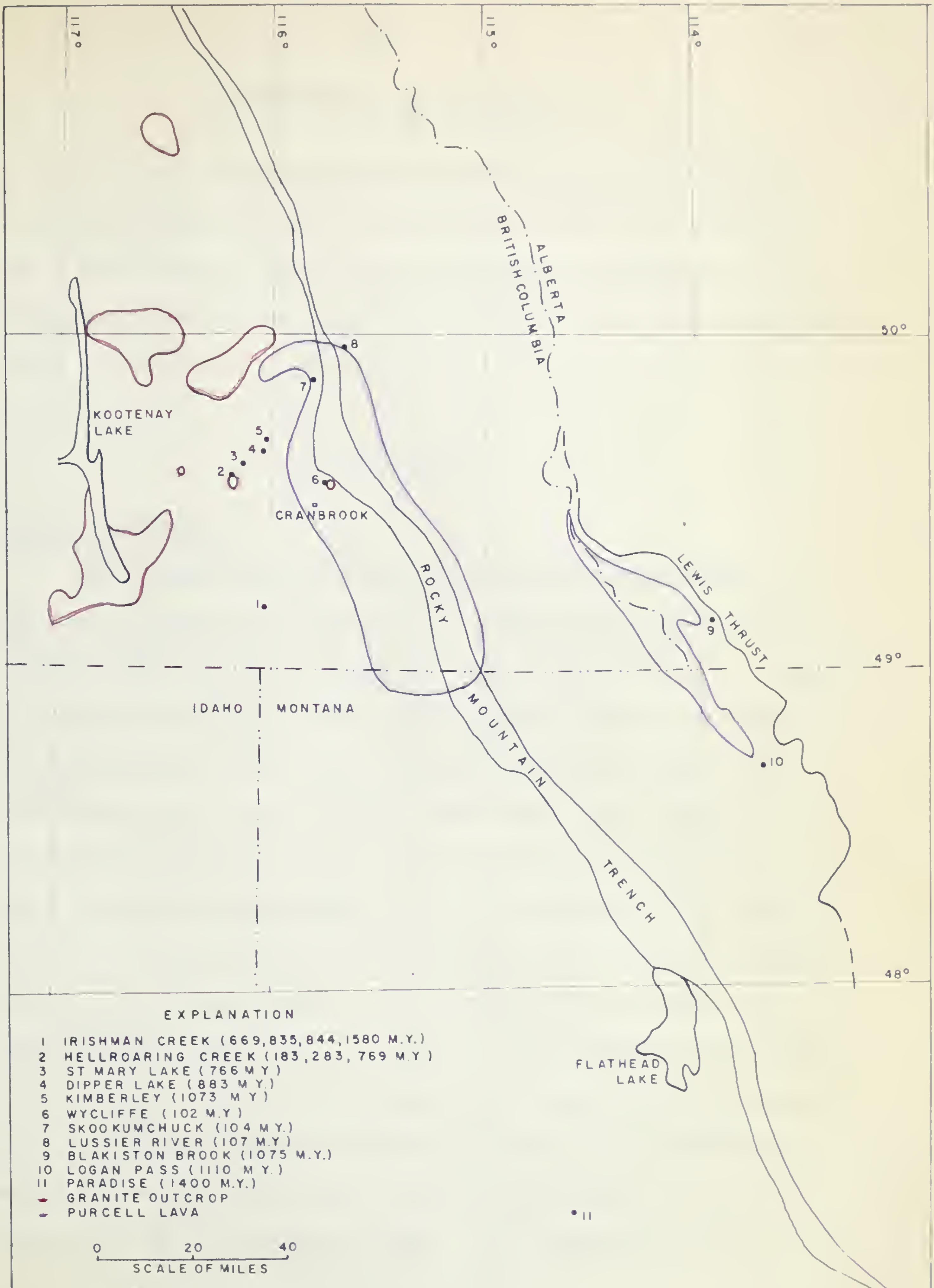


FIGURE 24 DISTRIBUTION OF DATED SAMPLES

INTERPRETATION AND COMPARISON

The potassium-argon age determinations, plotted in Figures 23 and 24, are grouped into four main geological events. The interpretation of these absolute ages is highly speculative but the writer feels that this grouping appears to be the best match for the complex geological history of the area.

Western Area

Irishman Creek, B.C.

The contacts of the Irishman Creek sill are well exposed. In thin section biotite has replaced the hornblende of the lower contact rock found below the sill. Within the lower margin of the sill, biotite has replaced some of the earlier-formed amphibole and biotite. These secondary biotites of the contact rock and the sill gave ages of 844 million years and 835 million years respectively. This suggests the occurrence of a metamorphic event about 800 million years ago and is called the East Kootenay orogeny, using the terminology of W.H. White, 1959, p. 63. Strong oxidation and weathering effects may have altered the ratio of the decay products in the biotite from the quartz vein above the upper contact since it appears to have undergone argon leakage.

The date of 1580 million years for the amphibole found well within the sill may indicate that the metamorphic grade of the East Kootenay orogeny was not above the biotite facies at this locality and the amphibole was able to retain its argon. It is assumed that the

absolute age of 1580 million years for the amphibole in the sill is the age of crystallization of that mineral and therefore dates the time of intrusion for this sill.

St. Mary Lake Area, B.C.

The St. Mary Lake area has undergone a complex and prolonged geological history. There has been a considerable amount of detailed mapping in the area (Leech, 1957), probably because of the occurrence of large sulphide deposits at Kimberley, B.C.

K-Ar age determinations by the Geological Survey of Canada (Lowdon, 1960, p. 5) gave biotite ages of 765 million years and 580 million years for a lamprophyre at the Sullivan Mine, B.C.

Cumming and others (1955) determined the isotopic composition of lead from galena samples at the Sullivan Mine. The isotope ratios indicated a probable age of 1050 $\pm$ 200 million years for the lead. The time of crystallization of the galena may be later than this date.

An isotope ratio analysis of the leads from the Sullivan Mine by R.L. Stanton and R.D. Russell (1959, p. 588) indicated that the date of the galena-bearing deposits may give the age of the sediments enclosing them. Their data gives a date of about 1300 million years for the lead samples.

Swanson and Gunning (1945) have reported pre-mineralization Purcell sills at the Sullivan Mine.

The writer obtained a K-Ar date of 1073 million years for amphibole from a sill near 3700 haulage, Sullivan Mine.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

G.B. Leech (in Lowdon, 1961, p. 6) reported the occurrence of a mica-bearing granodioritic stock on Hellroaring Creek which gave a potassium-argon age of 705 million years. The writer subsequently collected a muscovite sample from the same stock on Hellroaring Creek which gave an age of 769 million years (see Figure 18). This granite cuts the Aldridge formation and the Purcell sills.

Areas of garnetiferous, sillimanite schist are found grading into Aldridge quartzites to the east of Bootleg Mountain. These areas are believed to be parts of a metamorphic aureole above a granite stock (Schofield, 1915, p. 27).

The Hellroaring Creek granites and the metamorphic schists along the St. Mary River valley may be associated with the East Kootenay orogeny, which occurred about 800 million years ago.

The ages of 766 million years for the St. Mary Lake sill amphibole and the 883 million years date for the Dipper Lake sill amphibole appear to coincide with the age dates of the Hellroaring Creek granite (769 m.y.). Assuming that the time of intrusion of the sills in the St. Mary Lake area was before the granite intrusion, the dates of 766 million years and 883 million years for the amphiboles from the St. Mary Lake and Dipper Lake sills may reflect argon leakage from the heating effect of the nearby granites.

Schofield (1914, p. 8) believed that the hornblende in the St. Mary Lake "B" sill is secondary after pyroxene and attributed the pyroxene-hornblende transition to metamorphism. Since the writer could not find the primary pyroxene it has not been possible to determine the time of pyroxene crystallization and subsequent alteration to hornblende.

If there is an axis of metamorphism and intrusion striking parallel to the St. Mary River valley, the effect of this zone would decrease spatially to the north, that is, away from the "hot" zone. The Dipper Lake sill is located about 2 1/2 miles to the north of the valley and the Kimberley sill is located about 5 miles to the north of the valley. Therefore, it may be argued that the intensity of the heating effect decreases to the northeast over a distance of 5 miles, if this effect is represented by the increase of age dates from 766 to 1073 m.y.

However, the possibility exists that these amphibole dates from within the sills could represent the time of intrusion in this area. The Kimberley sill may be the intrusive equivalent of the Purcell lava.

An age of 183 million years was obtained for the biotite found in a hornfels located below a sill on Hellroaring Creek. On geological grounds this age date is interpreted to be too low for the time of intrusion of this basic intrusive rock.

Biotite from a hornfels developed near a small pegmatite on Hellroaring Creek gave an age of 283 million years. This age date does not coincide with the age reported for the mineralogically similar Hellroaring Creek stock. Petrographic descriptions of the pegmatite and the stock are almost identical. Since the stock gave an age of 769 million years, the age of 283 million years for the pegmatite is interpreted to be too low.

Rocky Mountain Trench Area, B.C.

At Bradfords quarry, about 1 mile north of Wycliffe, B.C., a biotite-bearing porphyritic granite is exposed cutting Lower Cambrian sediments (Schofield, 1915; Rice, 1937). Biotite from this granite gave an age of 102 million years. This age may represent the time of granitic intrusion associated with the Coast Range Orogeny (White, 1959, p. 78).

At Skookumchuck Creek, B.C., biotite taken from a minette dyke which cuts the Purcell lava gave an age of 104 million years (see Figure 12).

At Lussier River, B.C., a whole rock sample of Purcell lava, taken near a strong fault zone, gave an age of 107 million years. The age obtained may date the time of faulting in this area but it is difficult to assess a whole rock sample age.

In conclusion, the ages obtained from the Wycliffe granite, minette dyke and the fault zone in the Rocky Mountain Trench area are interpreted to be associated with the time of the Coast Range orogeny. Larsen et al (1958) have found the Coast Range intrusive complex to average about 108 million years of age by lead-alpha dating.

Eastern Area

Glacier Park, Montana

Primary, brown hornblende from a thin sill in the Siyeh formation at Logan Pass, gave an age of 1110 million years. The amphibole date is interpreted to give the time of intrusion for the well exposed diabase sill (see Figure 4).

A K-Ar age of 740 million years was reported by S.S. Goldich et al (1959, pp. 654-662) for an illite sample from the Siyeh limestone, Logan Pass, Montana. This illite bed occurs about 1/4 mile to the west of the Logan Pass Sill and is about 1200 feet stratigraphically above the sill (graphic calculation). S.S. Goldich et al (1959, p. 658) stated, ".... the heavy-mineral fraction contains zircon and rare biotite and apatite and in this respect the Belt shale is similar to clays derived from volcanic material. It seems likely that the Belt illite was formed from a volcanic ash in a manner analogous with the K-bentonites." Possibly the age of 740 million years represents the effects of the East Kootenay orogeny (White, 1959, p. 67), on an ash bed associated with the Purcell lava vulcanism.

Waterton Park, Alberta

Recent studies by the writer on the basic, igneous amygdaloidal rocks found on Ruby Ridge and Blakiston Brook suggest that these rocks, mapped as sills by Douglas (1952) in the Appekunny and Grinnell formations, are actually flow rocks (see page 46, Chapter IV).

An age of 1075 million years was obtained on a sericite-bearing hornfels zone found at the base of the Blakiston Brook flow in the Grinnell formation. The flow is about 3500 feet below the Purcell lava formation.

Southern Area

A.L. Anderson (1952) made a definite distinction between the pre-mineralization diabase rocks and the post-mineralization lamprophyre dykes in the Coeur d'Alene area, Idaho.

The age of 1400 million years determined for the amphibole from the Paradise sills (Located about 70 miles to the east of the Sunshine Mine, Idaho) may represent the time of intrusion of the pre-mineralization diabase intrusive rocks in the Coeur d'Alene Area, Idaho.

P.F. Kerr and P.F. Robinson (1953) noted that the uraninite veins of the Sunshine Mine are oriented parallel to bedding and fracture cleavage directions. The sulphide mineralization is oriented parallel to faults which cut across bedding and fracture cleavage structures at small angles. They concluded that uranium mineralization preceded sulphide deposition.

W.R. Eckelman and J.L. Kulp (1957) conclude that the Belt series (Proterozoic) rocks are at least 1190 million years old on the basis of analyses of two samples of pitchblende from the Sunshine Mine in the Coeur d'Alene district of Idaho. The age of the Sunshine uraninite has been recalculated to a 1200 million years minimum instead of the previously reported date of 750 million years.

SUMMARY

The writer feels that the potassium-argon age determinations, which are plotted in Figures 23 and 24, may be grouped into four main geological events.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Early Purcell Plutonism

K-Ar ages of 1580 million years and 1400 million years for amphiboles from the Irishman Creek sill and the Paradise sill respectively, are the oldest dates in the thesis area. These ages differ, but are within estimated analytical error. There is no absolute age data to suggest the occurrence of associated extrusive equivalents of the Irishman and Paradise sills. The known areal extent of the Purcell lava is shown in Figure 24. No basaltic extrusions occur at the Purcell lava stratigraphic level, in the Paradise area or in the area to the west of Irishman Creek (Rice, 1941).

Late Purcell Plutonism and Volcanism

K-Ar ages of 1110 million years, 1075 million years and 1073 million years for the Logan Pass sill, the Blakiston Brook hornfels and the Kimberley sill respectively are all within estimated analytical error. The age of the Blakiston Brook hornfels suggests a time of basaltic extrusion about 1050 million years ago in the eastern Purcell terrain. Since the Purcell lava is the only Precambrian basaltic extrusion exposed in the Kimberley area, the time of intrusion of the Kimberley sill may also date the time of extrusion of the Purcell lava in the western Purcell terrain.

East Kootenay Orogeny

An age of 769 million years was obtained for the time of intrusion of the Hellroaring Creek stock in the St. Mary Lake area. This granitic stock cuts the Purcell intrusions on Hellroaring Creek. The two values of 766 million years and 883 million years determined for the amphiboles from the St. Mary Lake sill and the Dipper Lake sill reflect argon leakage caused by the heating effect of these granitic rocks.

Biotite ages of 844 million years and 835 million years from Irishman Creek coincide with the age of the St. Mary Lake granitic activity. This suggests a regional Precambrian metamorphic event in the area which is called the East Kootenay Orogeny (White, 1959).

Coast Range Orogeny

Biotites, taken from the Wycliffe granite and the Skookumchuck minette, gave K-Ar ages of 102 million years and 104 million years. A whole rock sample of Purcell lava from Lussier River, British Columbia gave an age of 107 million years. These ages are interpreted to be associated with the time of the Coast Range orogeny (Baadsgaard, et al., 1961).

Biotites which gave ages of 183 million years and 283 million years from the St. Mary Lake area, were probably affected by metamorphism of the Coast Range orogeny.

CHAPTER VII - CONCLUSIONS

On the basis of a study of the field relations, petrography, chemistry and absolute age of the Purcell eruptive rocks, the author has reached the following major conclusions:

1. At least two major periods of Purcell intrusion occurred.
2. Two Purcell petrographic provinces exist.
3. Since the time of emplacement, the Purcell eruptive rocks have undergone a complex metamorphic history.

The geological history of the thesis area can be interpreted in terms of the following sequences of events. Initial Purcell intrusion probably occurred in the western part of the thesis area soon after the deposition of the dominantly fine-grained quartzites and siltstones of the Fort Steele and Aldridge formations. At the time of intrusion, these water-rich sediments were probably very pliant in nature and permitted the injection of concordant igneous masses along the bedding planes. The yielding of the sediments might account for the rarity of dykes in the Fort Steele and Aldridge formations. Sills are more numerous and thicker in these two lower Purcell formations than in any other formation in the thesis area. To the north of the thesis area, Leech (1958b) mapped a few sills in the Kitchener formation. There may be a relationship between the stratigraphic environment and the age of sill intrusion but the Kitchener sills were not sampled in this study. All of the sills studied by the author in the western part of the thesis area are found in the Aldridge formation. They are classified as quartz diabases and are dominantly composed of amphibole, altered plagioclase feldspar and quartz. The hydrous nature of the enclosing strata could have provided much of the water needed

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

in the formation of the amphiboles, which make up over 50 per cent of the sills. It is significant to note that the contact rocks adjacent to the sills are also amphibole-rich. In some sills there may be two different types of amphibole with one amphibole a primary magmatic mineral and the other secondary after pyroxene (Rice, 1941).

Although most of the sills in the Purcell Mountains were probably intruded early in the Purcell sedimentary cycle, differences in mineralogy of the sills suggests that intermittent intrusive activity may have continued throughout Lower Purcell time. The mineralogy of the St. Mary Lake sill and the Dipper Lake sill differs from that of the Irishman Creek sill. Pyroxene was found in the St. Mary Lake sill (Schofield, 1915) but not in the Irishman Creek sill where primary biotite is one of the dominant minerals. Normative olivine is calculated in the St. Mary Lake sill but not in the Irishman Creek sill. Potassium-argon data suggests the Irishman Creek sill was intruded about 1500 million years ago and the St. Mary Lake type sills were intruded about 1100 million years ago.

Correlations of the sedimentary rocks represented by the Purcell system suggest that sedimentation began in the west and extended eastward (Reesor, 1957a, p. 157). The fine-grained argillaceous and quartzitic rocks of the Lower Purcell grade into a more calcareous succession in the Upper Purcell.

In the Lewis Series, local pyroxene-bearing flows occur in the Appekunny and Grinnell formations. These thin flows are locally porphyritic, with feldspar laths up to 80 mm. in length. The feldspars consist of zoned plagioclase, ranging in composition from An_{70} to An_{27}, and potash feldspar. The pyroxenes have compositions similar to those given by Turner

and Verhoogen (1960) for alkaline olivine basalt. Olivine pseudomorphs form up to 10 per cent of the Grinnell flow. No Purcell igneous rocks are reported in the basal formations of the Lewis Series in the thesis area.

Near the top of the Siyeh formation, basaltic extrusions occur which are believed to be submarine flows from fissures. The submarine mechanism of extrusion caused the flows to incorporate large, ellipsoidal-shaped accumulations of soft, yielding sedimentary material and minor basaltic pillows. Perhaps this submarine mechanism caused the chloritization of the early magmatic pyroxene and olivine of the flows.

The greatest thickness of Purcell lava formation is found near the 49th Parallel. The lava outcrops northward to about longitude 116 degrees and latitude 50 degrees (Reesor, 1957b). Daly (1912) noted a possible feeder to the Purcell lava near the 49th Parallel in the McGillivray range of the Purcell Mountains. The western known Purcell lava outcrop is centered near the southern part of the Rocky Mountain Trench. There are two main accumulations of basalt, separated by important thicknesses of Siyeh sediments. The lava is not found at the comparable stratigraphic level near Creston, B.C. (Rice, 1941). No exposures are seen east of the Galton Range to the Flathead Valley (Daly, 1912). Leech (1960) noted that the Purcell lava of the Galton range immediately east of the Trench corresponds to the lower main zone found just to the west of the Trench near the 49th Parallel. The Phillips formation which is found stratigraphically above the Purcell lava occurs on either side of the Trench (Leech, 1960).

Chemically, the western Purcell lava is a tholeiitic to olivine basalt. It appears to be distinct from the eastern Purcell alkaline extrusions. Petrographically, the western lavas are highly altered basalts with amygdaloidal and porphyritic phases. Olivine pseudomorphs are present. Much of the groundmass was probably a glass in origin. The western Purcell lavas are most abundant in the Cranbrook area where the exposure of intrusive equivalents might be expected. In the area of lava outcrop at Cranbrook, no sills or dykes similar to the Purcell intrusions are found in formations above the Siyeh formation (Rice, 1937). There are fine-grained dykes in the Kitchener formation similar to the lavas in appearance (Rice, 1937).

In the eastern Purcell terrain the Purcell lava formation thickens northward from zero thickness near Logan Pass, Montana to about 300 feet near the Carbondale River area. Pillow structures up to two feet in diameter are found in the basal parts of the flows. The upper parts of the flows are amygdaloidal, with irregular ropy surfaces. The amygdules are infilled with quartz, calcite, chlorite and iron oxide minerals. The lower contact zone is marked by a baked hornfelsic zone in the sediments. The flows are generally thin, ranging from 1 to 50 feet in thickness. Some local thin flows have been found in the overlying Sheppard and Kintla formations.

The sills of the eastern area are dominantly found in the Siyeh formation and differ markedly in composition with the sills of the western area which are found in the Aldridge formation. The eastern sills are thin and contain altered zoned plagioclase feldspar, ranging

[illegible]

[illegible]

[illegible]

in composition from labradorite cores to oligoclase rims. Augite and brown hornblende are the principal primary mafic minerals. The secondary minerals are: green hornblende, biotite, chlorite and epidote. Olivine pseudomorphs are present in minor amounts. Potash feldspar and quartz form granophyric textures.

Potassium-argon data suggest that the time of the late Purcell magmatism in both the western and eastern Purcells was about 1100 million years ago on the basis of the concordant dates of 1073 million years, 1075 million years and 1110 million years for the Kimberley sill, Blakiston Brook flow and the Logan Pass sill respectively. It is noted that other areas in North America may have undergone a similar period of basaltic magmatism on the basis of absolute age dates for the Duluth gabbro (1000 million years, Goldich et al, 1959b), diabase in Arizona (1075 million years, Silver, 1960), diabase in Sudbury (1020 million years, Fairbairn et al, 1960), and the Muskox Complex, Northwest Territories (1155 million years, Smith, 1961).

At least two major metamorphic events, the East Kootenay orogeny and the Coast Range orogeny, affected the Purcell igneous rocks. Post-Purcell-pre-Windermere granites cut the Purcell intrusions in the St. Mary Lake area. On the basis of K-Ar data the Hellroaring Creek stock was probably emplaced about 800 million years ago (Lowdon, 1961, this thesis). Amphiboles from the St. Mary Lake sill and the Dipper Lake sill give dates of 766 million years and 883 million years. Proximity of these sills to the Hellroaring Creek stock suggests that the amphiboles have lost argon due to thermal metamorphism. The time of intrusion of these sills may be either 1100 or 1500 million years ago. Biotites from the Irishman Creek

[illegible]

[illegible]

[illegible]

sill give dates concordant with the Hellroaring Creek granitic activity. Lamprophyres at the Sullivan Mine, which may be differentiates of the Hellroaring Creek granite, also give concordant dates of about 800 million years. The metamorphic event at 750 million years to 850 million years is here called the East Kootenay orogeny, using the terminology of White (1959).

Biotite from a porphyritic granitic stock cutting Cambrian sediments at Wycliffe, B.C. gave a date of 102 million years. Biotite taken from a minette dyke which cuts the Purcell lava at Skookumchuck Creek, B.C. gave a date of 104 million years. These dates are similar to the K-Ar dates obtained by Baadsgaard et al (1961) for the time of the Coast Range Orogeny. In the St. Mary Lake area, this orogeny is reflected in argon leakage of some of the hornfelsic biotites. The amphiboles from within the sills appear to have a much greater argon retentivity than the biotites. Assuming that the K-Ar dates indicate the last major heating of the rock from which the minerals used in dating were separated, a sound knowledge of the geological setting of the sample is required for a reliable interpretation to be made.

SELECTED BIBLIOGRAPHY

Anderson, A.L., 1930, Geology and ore deposits of the Clark Fork district: Idaho Bur. Mines & Geol. Bull. No. 12.

--------, 1952, Magmatic Source of Idaho ores: Northwest Science, v. 26, #2, p. 55-60.

Baadsgaard, H., Folinsbee, R.E., and Lipson, J., 1961, Potassium-argon dates of biotites from Cordilleran granites: Geol. Soc. America Bull., v. 72, p. 689-702.

Barth, T.F.W., 1952, Theoretical petrology: John Wiley & Sons, Inc., New York.

Berry, A.D., 1951, A study of the Aldridge formation, St. Mary Lake area, B.C.: Unpubl. M.Sc. thesis, University of Alberta.

Bowen, N.L., 1937, Recent high-temperature research on silicates and its significance in igneous geology: Am. Jour. Sci., v. 40, p. 161-185.

Burling, L.D., 1916, Ellipsoidal lavas in Glacier National Park, Montana: Jour. Geol., v. 24, p. 235-237.

Calkins, F.C. and MacDonald, D.F., 1909, A geological reconnaissance in northern Idaho and northwestern Montana: U.S. Geol. Survey Bull. 384.

Clapp, C.H. and Deiss, C.F., 1931, Correlation of Montana Algonician formations: Geol. Soc. America Bull., v. 42, p. 673-696.

Clapp, C.H., 1932, Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines & Geol., Mem. #4.

Cumming, G.L., Wilson, J.T., Farquhar, R.M. and Russell, R.D., 1955, Some dates and subdivisions of the Canadian Shield: Proc. Geol. Assoc. Canada, v. 7, pt. II.

Daly, R.A., 1912, Geology of the North American Cordillera at the 49th Parallel: Geol. Survey Canada Mem. 38, 546 p.

Douglas, R.J.W., 1952, Preliminary map, Waterton Alberta: Geol. Survey Canada Paper 52-10.

Eckelman, W.R. and Kulp, J.L., 1957, Uranium method of age determination: Geol. Soc. America Bull., v. 68, p. 1130.

Fairbairn, H.W., Hurley, P.M. and Pinson, W.H., 1960, Mineral and Rock ages at Sudbury-Blind River, Ontario: Geol. Assoc. Canada Proc., v. 12, p. 41-66.

Fenton, C.L. and Fenton, M.A., 1937, Belt series of the North; stratigraphy, sedimentation, paleontology: Geol. Soc. America Bull., v. 48, p. 1873-1969.

Finlay, G.I., 1902, Igneous rocks of the Algonkian Series: in Willis, B., 1902, Stratigraphy and structure, Lewis and Livingston Ranges, Montana: Geol. Soc. America Bull., v. 13, p. 349-352.

Gibson, R., 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geol. Survey Bull. 956.

Goldich, S.S., Baadsgaard, H., Edwards, G. and Weaver, C.E., 1959a, Investigations in radioactivity-dating of sediments: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 654-662.

Goldich, S.S., Nier, A.O., Hoffman, J.H. and Krueger, H.W., 1959b, Precambrian geochronology of Minnesota and adjacent areas (Abstract): Geol. Soc. America Bull., v. 70, p. 1609.

Grout, F.F., 1958, Kemp's handbook of rocks: D. Van Nostrand Co., Inc., New York.

Gunning, H.C., 1954, Igneous rocks in the southern Rocky Mountains of Canada: Alberta Soc. Petroleum Geologists Guidebook, 4th Ann. Conference, p. 137-140.

Hage, C.O., 1940, Beaver Mines map-area, Alberta: Geol. Survey Canada Map 739A.

Harker, A., 1932, Metamorphism: Methuen & Co., Ltd.

Hart, S.R., Fairbairn, H.W., Pinson, W.H. and Hurley, P.M., 1960, Use of amphiboles and pyroxenes for K-Ar dating (Abstract): Geol. Soc. America Bull., v. 71, p. 1882.

Hatch, F.H., Wells, A.K. and Wells, M.K., 1949, The petrology of igneous rocks: Thomas Murby & Co., London, 469 p.

Hayes, J.R. and Klugman, M.A., 1959, Feldspar staining methods: Jour. Sed. Pet., v. 29, p. 227-232.

Hess, H.H., 1949, Chemical composition and optical properties of common clinopyroxenes, Part I: Am. Mineralogist, v. 34, p. 621-666.

Hume, G.S., 1932, Waterton Lakes, Flathead area: Geol. Survey Canada Summary Rept., Part B, p. 1-20.

Hunt, G.H., 1958, Petrology of the Purcell sills in the St. Mary Lake area, B.C.: Unpub. M.Sc. thesis, University of Alberta.

Judd, J.W., 1886, On the gabbros, dolerites, and basalts of Tertiary age of Scotland: Quart. Jour. Geol. Soc., xlii, p. 34.

Jure, A.E., 1929, Petrology of the Purcell sills: Unpub. Ph.D. thesis, University of Wisconsin.

Kennedy, W.Q., 1933, Trends of differentiation in basaltic magma: Am. Jour. Sci., v. 25, p. 239-256.

Kennedy, G.C., 1947, Charts for correlation of optical properties with chemical composition of some common rock-forming minerals: Amer. Mineralogist, v. 32, p. 561-573.

Kerr, P.F. and Kulp, J.L., 1952, Precambrian uraninite, Sunshine Mine, Idaho: Science, v. 115, #2978, p. 86-88.

Kerr, P.F. and Robinson, P.F., 1953, Uranium mineralization in the Sunshine Mine, Idaho: Min. Eng., v. 5, p. 495-511.

Larsen, E.S., Gottfried, D., Jaffe, H.W. and Waring, C.L., 1958, Lead-alpha ages of the Mesozoic batholiths of western North America: U.S. Geol. Survey Bull. 1070-B, 27 p.

Leech, G.B., 1957, St. Mary Lake map-area, British Columbia: Geol. Survey Canada Map 15-1957.

--------, 1958a, Fernie map-area, British Columbia: Geol. Survey Canada, Map 20-1958.

--------, 1958b, Canal Flats map-area, British Columbia: Geol. Survey Canada Map 24-1958.

--------, 1959, The southern part of the Rocky Mountain Trench: Canadian Inst. Min. Met. Bull., v. LXIII, p. 152-172.

--------, 1960, Fernie map-area, British Columbia: Geol. Survey Canada Map 11-1960.

--------, 1961, Granodioritic stock: in Lord, C.S. and Jenness, S.E., Field Work, 1960, Geol. Survey Canada Circular #4.

Lowdon, J.A., 1960, Age determinations by the Geological Survey of Canada, Report 1, isotopic ages: Geol. Survey Canada, Paper 60-17.

--------, 1961, Age determinations by the Geological Survey of Canada, Report 1 isotopic ages: Geol. Survey Canada, Paper 61-17.

Macdonald, G.A., 1949, Hawaiian petrographic province: Geol. Soc. America, Bull., v. 60.

Mason, B., 1956, Principles of geochemistry: John Wiley and Sons, Inc., New York, 276 p.

Moorhouse, W.W., 1959, The study of rocks in thin section: Harper and Brothers, New York, 514 p.

Nockolds, S.R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, p. 1007-1032.

Norris, D.K., 1959, Carbondale River map-area, Alberta and British Columbia: Geol. Survey Canada Map 5-1959.

Olcott, G.W., 1960, Preparation and use of a gelatin mounting medium for repeated oil immersion of minerals: Am. Mineralogist, v. 45, p. 1099-1101.

Park, C.F. and Cannon, R.S., 1943, Geology and ore deposits of the Metaline quadrangle, Washington: U.S. Geol. Survey Prof. Paper 202.

Poldervaart, A., 1954, Chemistry of the earth's crust: Geol. Soc. America, Special Paper 62, 762 p.

Price, R.A., 1959, Flathead map-area, British Columbia and Alberta: Geol. Survey Canada Map 1-1959.

Reesor, J.E., 1953, Findlay Creek map-area, British Columbia: Geol. Survey Canada Map 34-1953.

--------, 1957a, The Proterozoic in Canada: Royal Soc. Canada Special Paper #2, p. 150-176.

--------, 1957b, Lardeau map-area, British Columbia: Geol. Survey Canada Map 12-1957.

--------, 1958, Dewar Creek map-area, British Columbia: Geol. Survey Canada Mem. 292.

Rice, H.M.A., 1937, Cranbrook map-area, British Columbia: Geol. Survey Canada Mem. 207, 67 p.

--------, 1941, Nelson map-area, East Half, British Columbia: Geol. Survey Canada Mem. 228, 86 p.

Ross, C.P., Andrews, D.A. and Witkind, I.J., 1955, Geological map of Montana: Montana Bur. Mines and Geology.

Ross, C.P., 1959, Geology of Glacier National Park and the Flathead Region, northwestern Montana: U.S. Geol. Survey Prof. Paper 296.

Schofield, S.J., 1914, The origin of granite (micropegmatite) in the Purcell sills: Geol. Survey Canada Museum Bull. #2, p. 1-34.

--------, 1915, Geology of Cranbrook map-area, British Columbia: Geol. Survey Canada Mem. 76, 245 p.

Scott, B., 1954, The diorite complex beneath the Sullivan orebody with its associated alterations: Unpub. M.Sc. thesis, Queens University.

Silver, L.T., 1960, Age determinations on Precambrian diabase differentiates in the Sierra Ancha, Gila County, Arizona (Abstract): Geol. Soc. America Bull., v. 71, p. 1973.

Smith, C.H., 1961, Muskox Complex: in Lord, C.S. and Jenness, S.E., Field Work, 1960: Geol. Survey Canada Information Circular #4, 53 p.

Stanton, R.L., and Russell, R.D., 1959, Anomalous leads and the emplacement of lead sulphide ores: Econ. Geol., v. 54, p. 588-607.

Sundius, N., 1930, On the spilitic rocks: Geol. Magazine, v. 67, p. 9.

Swanson, C.O. and Gunning, H.C., 1945, Geology of the Sullivan Mine: Canadian Min. Met. Bull. #402, p. 661-665.

Thornton, C.P. and Tuttle, O.F., 1960, Chemistry of igneous rocks, 1. Differentiation index: Am. Jour. Sci., v. 258, p. 664-684.

Turner, F.J., and Verhoogen, J., 1951, Igneous and metamorphic petrology: McGraw-Hill Book Company, Inc., New York, 602 p.

Turner, F.J. and Verhoogen, J., 1960, Igneous and metamorphic petrology: McGraw-Hill Book Company, Inc., New York, 694 p.

Walker, J.F., 1926, Geology and mineral deposits of Windermere map-area, British Columbia: Geol. Survey Canada Mem. 148, 69 p.

Warren, P.S., 1951, The Rocky Mountain geosyncline in Canada: Royal Soc. Canada Trans., v. XLV, Ser. II, Sec. 4.

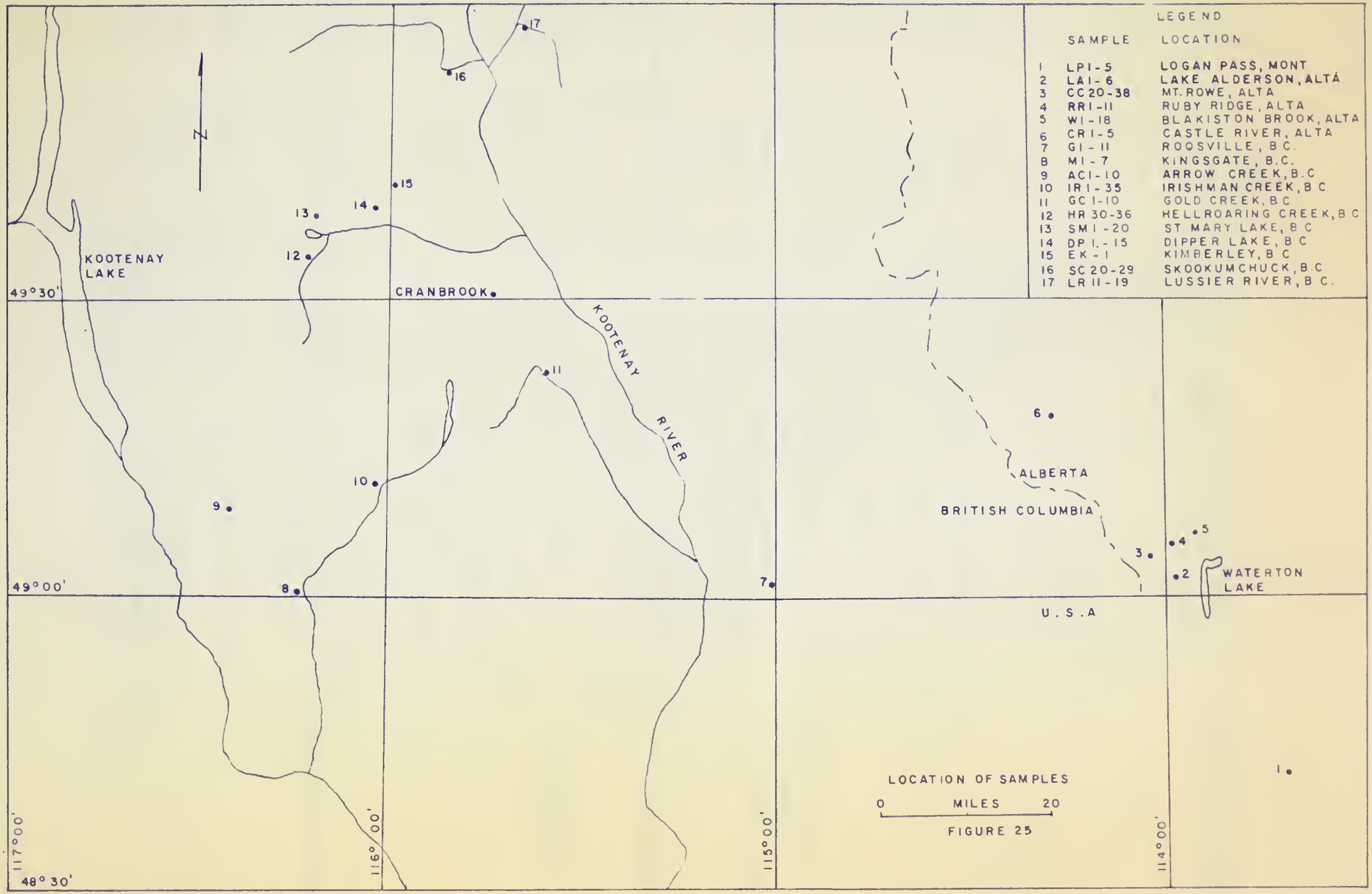
Washington, H.S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913: U.S. Geol. Survey Prof. Paper 99.

White, W.H., 1959, Cordilleran tectonics in British Columbia: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 60-100.

Willis, B., 1902, Stratigraphy and structure, Lewis and Livingston Ranges, Montana: Geol. Soc. America Bull., v. 13, p. 305-352.

APPENDIX A

THIN SECTIONS



LOCATION OF SAMPLES

FIGURE 25

Sample Number	Thin Section No.	Field Notes	Reference
		Location 1: Logan Pass area, Montana	C.P. Ross (1959)
	2998	Grinnell argillite, Going To The Sun Highway, Montana	
	2999	Diabase Sill, Going To The Sun Highway, Montana	
		Diabase Sill in Siyeh fm., near Pass, Going To The Sun Highway, 1959	
LP-1	4038a	Siyeh argillite, above upper contact with sill	
LP-2	4038b	Hornfels, at upper contact with sill	
LP-3	4038c	Diabase sill, 1 foot below upper contact of sill	
LP-4	4038d	Diabase sill, 10 feet below upper contact of sill	
LP-5	4038e	Siyeh illite summit, Logan Pass, Montana	
		Lewis Series, 1959	
	4039	Waterton fm., Cameron Creek, Alta, near Altyn fm. contact	R.J.W. Douglas (1952)
	4040	Altyn fm., St. Mary Lake, Montana	C.P. Ross (1959)
	4041	Appekunny fm., St. Mary Lake, Montana	
	4042	Grinnell fm., St. Mary Lake, Montana	
	4043a	Siyeh fm., Going To The Sun Highway, Mont.	
	4043b	Siyeh fm., Going To The Sun Highway, Mont.	
		Location 2: Lake Alderson, Alberta, 1957 Diabase sill in Siyeh limestone	
LA-1	3175	Siyeh fm., below lower contact with diabase sill	R.J.W. Douglas (1952)
LA-2	3176	Siyeh fm., at lower contact of sill with limestone	
LA-3	3177	Diabase sill, 5 feet above lower contact of sill	
LA-4	3178	Diabase sill, coarse phase in center of sill	
LA-5	3179	Diabase sill, 5 feet below upper contact of sill	
LA-6	3180	Upper contact of sill with Siyeh limestone	
		Location 3: Mt. Rowe, Alberta, 1958 Purcell lava section	
CC-20	3463	Sheppard fm., 5 feet above upper contact of lava	
CC-21	3464	Purcell lava, near upper contact of lava	
CC-22	3465	Purcell lava, 20' below upper contact of lava	
CC-23	3466	Purcell lava, 40' below upper contact of lava	
CC-24	3467	Purcell lava, 45' below upper contact of lava	

CC-25	3468	Purcell lava, 65' below upper contact of lava
CC-26	3469	Purcell lava, 80' " " " " "
CC-27	3470	Purcell lava, 110' " " " " "
CC-28	3471	Purcell lava, 125' " " " " "
CC-29	3472	Purcell lava, 135' " " " " "
CC-30	3473	Purcell lava, 145' " " " " "
CC-31	3474	Purcell lava, 175' " " " " "
CC-32	3475	Purcell lava, 185' " " " " "
CC-33	3476	Purcell lava, 210' " " " " "
CC-34	3477	Purcell lava, 230' " " " " "
CC-35	3478	Purcell lava, 255' " " " " "
CC-36	3479	Purcell lava, 285' " " " " "
CC-37	3480	Purcell lava, at lower contact of lava with sediment
CC-38	3481	Siyeh fm., 100' below lower contact of lava

Cameron Creek, about 1 mile southeast of Mt. Rowe Section

	3482	Purcell lava, lower contact of lava with sediments
	3483	Purcell lava, 1' above lower contact

<u>Location 4</u>: Ruby Ridge, Alberta, 1959
Diabase in Appekunny fm. R.J.W. Douglas (1952)

RR-1	4037a	Appekunny fm., 1' below lower contact with diabase
RR-2	4037b	Appekunny fm., lower contact with diabase
RR-3	4037c	Diabase, 1' above lower contact with sediment
RR-4	4037d	Diabase, 5' " " " " "
RR-5	4037e	Diabase, 10' " " " " "
RR-6	4037f	Diabase, 25' " " " " "
RR-7	4037g	Diabase, 30' " " " " "
RR-8	4037h	Diabase, 35' " " " " "
RR-9	4037i	Amygdaloidal lava, 5' below upper contact with sediment
RR-10	4037j	Amygdaloidal lava, 1' " " " " "
RR-11	4037k	Appekunny fm., upper contact with amygdaloid

<u>Location 5</u>: Blakiston Brook, Alberta, 1957, 1960
Diabase in Grinnell fm.

W-1	3059	Grinnell fm., 100' below lower contact of diabase	R.J.W. Douglas (1952)
W-2	3060	Grinnell fm., 2' below lower contact	
W-3	3061	Grinnell fm., 1' " " "	
W-4	3062	Grinnell fm., Lower contact	
W-5	3063	Diabase, 5' above lower contact	
W-6	3064	Diabase, 10' " " "	
W-7	3065	Diabase, 15' " " "	
W-8	3066	Diabase, 20' " " "	
W-9	3067	Diabase, 20' below upper contact	
W-10	3068	Diabase, 5' " " "	

W-11	3069	Upper contact with Grinnell fm.
W-12	3070	Grinnell fm., 3' above upper contact of diabase
W-13	3071	Grinnell fm., 10' " " " " "
W-14	4360-1	Lower contact with Grinnell fm.
W-15	4360-2	Diabase, above lower contact
W-16	4360-3	Grinnell fm., 3' below lower contact
W-17	4360-4	Diabase, near upper contact
W-18	4360-4B	Diabase, " " "

NOTE: Samples BB-1 to BB-4B are numbered W14-W18

Location 6: Castle River, Alberta, 1960
Purcell Lava Section D.K. Norris (1959)

CR-1	4358-1	Siyeh fm., algal bed, 400' below lower contact of lava
CR-2	4358-2	Siyeh fm., "balled-up" structures, 40' below lower contact of lava
CR-3	4358-3	Siyeh fm., lower contact of lava with sediments
CR-3A	4358-3A	Siyeh fm., " " " " " "
CR-4	4358-4	Ellipsoidal sediments enclosed in Purcell lava
CR-5	4358-5	Purcell lava, near lower contact
CR-5A	4358-5A	Purcell lava, enclosing sediment, near lower contact

Location 7: Roosville, B.C., 1960
Purcell Lava Section G.B. Leech (1960)

G-1	4359-1	Gateway fm., algal bed, 100' above upper contact of lava
G-2	4359-2	Gateway fm., quartzite, 75' " " " " "
G-3	4359-3	Gateway fm., quartzite, 25' " " " " "
G-5	4359-5	Purcell lava, 12' below upper contact of lava
G-6	4359-6	Purcell lava, 15' " " " " "
G-7	4359-7	Purcell lava, 60' " " " " "
G-8	4359-8	Purcell lava, 100' " " " " "
G-9	4359-9	Purcell lava, 170' " " " " "
G-10	4359-10	Purcell lava, 350' " " " " "
G-11	4359-11	Purcell lava, 410' " " " " "

Location 8: Kingsgate, B.C., 1957
Moyie "A" sill in Aldridge fm. R.A. Daly (1912)

M-1	2903	Diabase sill, 32' above lower contact of sill
M-2	2904	Diabase sill, 10' " " " " "
M-3	2905	Diabase sill, near base of sill
M-4	2906	Aldridge fm., lower contact of sill with quartzite
M-5	2907	Aldridge fm., 5' below lower contact of sill
M-6	2908	Aldridge fm., 35' " " " " "
M-7	2909	Aldridge fm., 600' " " " " "

Location 9: Arrow Creek, B.C., 1959 H.M.A. Rice (1941)
Diabase in Aldridge quartzite

AC-1	3894a	Diabase, lower sill, 50' south of coarse-grained phase
AC-2	3894b	Diabase, lower sill, 30' " " " " "
AC-3	3894c	Diabase, lower sill, 5' " " " " "

AC-4	3894d	Diabase, lower sill, 60' north of coarse-grained phase	
AC-5	3894e	Diabase, lower sill, 140' " " " " "	
AC-6	3894f	Diabase, lower sill, 200' " " " " "	
AC-7	3894g	Diabase, middle sill, central coarse-grained phase	
AC-8	3894h	Diabase, upper sill, 60' north of coarse-grained phase	
AC-9	3894i	Diabase, upper sill, 90' " " " " "	
AC-10	3894j	Diabase, middle sill, 150 " " " " "	
		Location 10: Irishman Creek, B.C., 1959, 1960 Diabase sill in Aldridge fm.	
IR-1	3863a	Aldridge fm., 1 foot below lower contact of sill	H.M.A. Rice
IR-2	3863b	Aldridge fm., 8 inches " " " " "	(1941)
IR-3	3863c	Aldridge fm., 4 inches " " " " "	
IR-4	3863d	Diabase sill, base of sill	
IR-5	3863e	Diabase sill, 5' above lower contact of sill	
IR-6	3863f	Diabase sill, 10' " " " " "	
IR-7	3863g	Diabase sill, 15' " " " " "	
IR-8	3863h	Diabase sill, 2' below upper contact of sill	
IR-9	3863i	Aldridge fm., 2' above " " " "	
IR-10	3863j	Biotite-quartz vein at upper contact of sill	
IR-11	4357-11	Aldridge fm., 1 foot below lower contact of sill	
IR-12	4357-12	Aldridge fm., 2' " " " " "	
IR-13	4357-13	Aldridge fm., 3' " " " " "	
IR-14	4357-14	Aldridge fm., 4' " " " " "	
IR-15	4357-15	Aldridge fm., 7' " " " " "	
IR-16	4357-16	Aldridge fm., 15' " " " " "	
IR-17	4357-17	Aldridge fm., 50' " " " " "	
IR-18	4357-18	Aldridge fm., 80' " " " " "	
IR-19	4357-19	Diabase sill, 2' above lower contact of sill	
IR-20	4357-20	Diabase sill, 3' " " " " "	
IR-21	4357-21	Diabase sill, 6' " " " " "	
IR-22	4357-22	Diabase sill, 8' " " " " "	
IR-23	4357-23	Diabase sill, 10' " " " " "	
IR-24	4357-24	Diabase sill, 13' " " " " "	
IR-25	4357-25	Diabase sill, 15' " " " " "	
IR-26	4357-26	Diabase sill, 20' " " " " "	
IR-27	4357-27	Diabase sill, 22' " " " " "	
IR-28	4357-28	Diabase sill, 24' " " " " "	
IR-29	4357-29	Diabase sill, 25' " " " " "	
IR-30	4357-30	Aldridge fm., 1' above upper contact of sill	
IR-31	4357-31	Aldridge fm., 1.6' " " " " "	
IR-32	4357-32	Aldridge fm., 2' " " " " "	
IR-33	4357-33	Aldridge fm., 5' " " " " "	
IR-33A	4357-33A	Aldridge fm., 35' " " " " "	
IR-34	4357-34	Aldridge fm., 50' " " " " "	
IR-35	4357-35	Aldridge fm., 100' " " " " "	

<u>Location 11</u>: Gold Creek, B.C., 1959 — Purcell Lava Section — G.B. Leech (1960)

GC-1	3895a	Gateway fm., 100' above upper contact of lava
GC-2	3895b	Gateway fm., 5' " " " " "
GC-3	3895c	Purcell lava, 20' below upper contact of lava
GC-4	3895d	Purcell lava, 100' " " " " "
GC-5	3895e	Purcell agglomerate, 720' below upper contact of lava
GC-6	3895f	Siyeh fm., 50' below agglomerate
GC-7	3895g	Purcell lava, 350' above lower contact of lava
GC-8	3895h	Purcell lava, 150' " " " " "
GC-9	3895i	Purcell lava, 25' " " " " "
GC-10	3895j	Siyeh fm., 10' below lower contact of lava

<u>Location 12</u>: Hellroaring Creek, B.C., 1959, 1960 — Granitic stocks cutting diabase sills — G.B. Leech (1957)

HR-30	3886	Aldridge fm., contact zone of pegmatite
HR-31	3887	Pegmatite
HR-32	3888	Diabase sill, upper coarse phase of thick sill (200')
HR-33	3889	Diabase sill, near base of thin sill (10')
HR-33A	3890	Aldridge fm., upper contact zone of thin sill
HR-34	3891	Diabase sill, near base of sill cut by pegmatite
HR-36	HR-36	Granite, Warhorse mining road near bridge

<u>Location 13</u>: St. Mary Lake, B.C., 1957 — St. Mary Lake sills — G.B. Leech (1957)

SM-1	2887	Diabase sill, Boot Leg mtn., west of Resort Creek	
SM-2	2888	Diabase sill, " " " " " " "	
SM-3	2889	Diabase sill, " " " " " " "	
SM-4	2890	Diabase sill, " " " " " " "	
SM-5	2891	Diabase sill, " " " " " " "	
SM-6	2892	Diabase sill, " " " " " " "	
SM-7	2893	Aldridge fm., 7' above upper contact of "A" sill	S.J. Schofield
SM-8	2894	Aldridge fm., 1' " " " " " "	(1915)
SM-9	2895	Aldridge fm., upper contact	
SM-10	2896	Diabase sill, 4' below upper contact of "A" sill	
SM-11	2897	Diabase sill, 15' " " " " " "	
SM-12	2898	Diabase sill, 30' " " " " " "	
SM-13	2899	Diabase sill, 40' " " " " " "	
SM-14	2900	Diabase sill, 80' " " " " " "	
SM-15	2901	Diabase sill, 150' " " " " " "	
SM-16	2902	Diabase sill, 220' " " " " " "	
SM-17	3060	Aldridge fm., 3' above upper contact of "A" sill	
SM-18	3061	Aldridge fm., 5' " " " " " "	
SM-19	3062	Aldridge fm., 14' " " " " " "	
SM-20	3063	Diabase sill, near base of "B" sill	

		Location 14: Dipper Lake, B.C., 1959 G.B. Leech (1957) Thick diabase sill in Aldridge fm.
DP-1	3893a	Aldridge fm., 8' below lower contact of sill
DP-2	3893b	Aldridge fm., 4' " " " " "
DP-2A	3893c	Aldridge fm., lower contact zone
DP-3	3893d	Aldridge fm., " " "
DP-4	3893e	Diabase sill, 1' above lower contact of sill
DP-5	3893f	Diabase sill, 5' " " " " "
DP-6	3893g	Diabase sill, 15' " " " " "
DP-7	3893h	Diabase sill, 50' " " " " "
DP-8	3893i	Diabase sill, 80' " " " " "
DP-9	3893j	Diabase sill, 105' " " " " "
DP-10	3893k	Diabase sill, 160' " " " " "
DP-11	3893l	Diabase sill, 215' " " " " "
DP-12	3893m	Diabase sill, 270' " " " " "
DP-13	3893n	Diabase sill, 330' " " " " "
DP-14	3893o	Diabase sill, 390' " " " " "
DP-15	3893p	Diabase sill, near upper contact of sill
DP-35	3892	Diabase sill, St. Mary Lake road junction with Dipper Lake
		Location 15: Kimberley, B.C., 1957 H.M.A. Rice (1937)
EK-1		Diabase sill, 3700 haulage, Sullivan Mine
		Location 16: Skookumchuck Creek, B.C., 1959 Purcell Lava Section G.B. Leech (1960)
SC-20	3866	Siyeh fm., 40' below lower contact of lava
SC-21	3867	Lower contact of Purcell lava with sediments
SC-22	3868	Purcell Lava, 1' above lower contact of lava
SC-23	3869	Purcell Lava, 140' " " " " "
SC-24	3870	Siyeh fm., 220' " " " " "
SC-25	3871	Minette dyke, 405' " " " " "
SC-26	3872	Purcell lava, 420' " " " " "
SC-27	3873	Purcell lava, 550' " " " " "
SC-28	3874	Dutch Creek fm., 610' above lower contact of lava
		Location 17: Lussier River, B.C., 1959 Purcell Lava Section G.B. Leech (1960)
LR-11	3875	Gateway fm., near upper contact of Purcell lava
LR-12	3876	Purcell lava, upper contact of lava
LR-12A	3877	Purcell lava, " " " "
LR-13	3878	Purcell lava, 25' below upper contact of lava
LR-14	3879	Purcell lava, 50' below upper contact of lava with Gateway
LR-15	3880	Agglomerate, 125' " " " " " " "
LR-16	3881	Purcell lava, 160' above lower contact of lava with Siyeh
LR-17	3882	Purcell lava, 80' " " " " " " "
LR-18	3883	Purcell lava, 50' " " " " " " "
LR-18A	3884	Purcell lava, lower contact of lava
LR-19	3885	Siyeh fm., near lower contact of lava

Purcell System

	4361-1	Aldridge fm., Highway 3, 12 miles north of Moyie, B.C.	G.B. Leech (1960)
	4361-2	Creston fm., Highway 3, 3 miles north of Moyie,B.C.	
	4361-3	Kitchener fm., Highway 3, 6 miles " " " "	
	4361-4	Siyeh fm., Wynndel, B.C.	H.M.A.Rice (1941)
	4361-5	Dutch Creek fm., Drywash Creek, B.C.	

Diabase sills in Montana, 1959

	3860a	Blackfoot diabase sill, G.S.A. Field Guide Book (1959), Missoula, Montana, p. 4.	
	3860b	Blackfoot diabase sill, G.S.A. Field Guide Book (1959), Missoula, Montana, p. 4.	
	3861a	Milltown diabase, G.S.A. Field Guide Book (1959), Missoula, Montana, p. 9.	
	3861b	Milltown diabase, G.S.A. Field Guide Book (1959), Missoula, Montana, p. 9.	
	3862a	Prichard fm., near contact of diabase sill, Paradise, Montana, C.P. Ross (1955).	
PM-1	3862b	Paradise sill, Highway, north of Paradise, Montana, C.P. Ross (1955).	

EXPLANATION OF PLATE 1

Photographs of Hand Specimens

Figure 1: Siyeh fm.--Laminated argillite, below lower contact of Purcell lava fm. Approximately 1/2 natural size. Skookumchuck Creek section; sample No. SC-20.

Figure 2: Siyeh fm.--Interbedded and laminated argillite and tuff. Approximately 2/3 natural size. Skookumchuck Creek section; sample No. SC-24.

Figure 3: Siyeh fm.--Low angle laminations of tuff. Approximately 4/5 natural size. Gold Creek section; sample No. GC-6.

Figure 4: Aldridge fm.--Quartz-biotite vein, above upper contact of diabase sill. Approximately 9/10 natural size. Irishman Creek section; sample No. IR-10.

Figure 5: Aldridge fm.--Biotite hornfels, 4 inches below lower contact of diabase sill. Approximately 4/5 natural size. Irishman Creek section; sample No. IR-3.

Figure 6: Aldridge fm.--Hornblende hornfels, 8 inches below lower contact of diabase sill. Approximately 4/5 natural size. Irishman Creek section; sample No. IR-2.

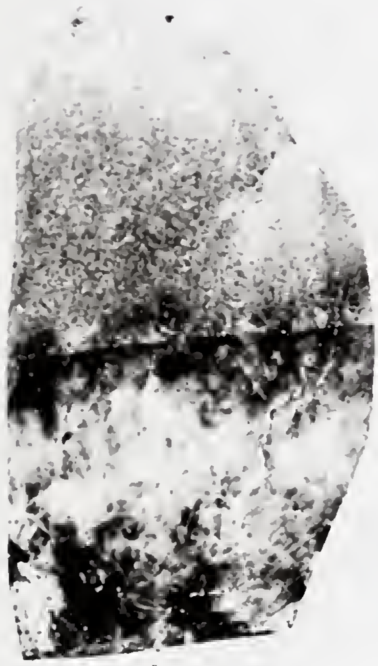
Figure 7: Gateway fm.--Algaloid structures, immediately above Purcell lava. Approximately 7/10 natural size. Gold Creek section; sample No. GC-2.

Figure 8: Siyeh fm.--Intraformational edgewise breccia with angular basaltic phenoclasts and sedimentary material. Approximately 8/10 natural size. Gold Creek section; sample No. GC-5.

1.

2.

3.



4.

5.

6.

7.

8.

PLATE I

EXPLANATION OF PLATE 2

Photographs of Hand Specimens

Figure 1: Minette dyke with biotite phenocrysts. Approximately 9/10 natural size. Skookumchuck Creek section; sample No. SC-25.

Figure 2: Lower contact of Purcell lava with Siyeh argillite. Approximately 9/10 natural size. Skookumchuck Creek section; sample No. SC-21.

Figure 3: Lower contact of pegmatite with Aldridge fm. Approximately 7/10 natural size. Hellroaring Creek; sample No. HR-30.

Figure 4: Lower contact of Purcell lava with Siyeh argillite. Approximately 9/10 natural size. Mt. Rowe section; sample No. CC-37.

Figure 5: Purcell lava fm.:--Amygdaloidal flow, near upper contact with Sheppard fm. Approximately 9/10 natural size. Mt. Rowe section; sample No. CC-21.

Figure 6: Lower contact of sill with Aldridge quartzite. Approximately 9/10 natural size. Dipper Lake section; sample No. DP-3.

Figure 7: Upper coarse phase of sill. Approximately 4/5 natural size. Dipper Lake section; sample No. DP-14.

Figure 8: Upper contact of sill. Approximately 9/10 natural size. Dipper Lake section; sample No. DP-15.

PLATE 2

EXPLANATION OF PLATE 3

Photomicrographs of Thin Sections

Figure 1: Purcell lava fm.--Microporphyritic, altered plagioclase feldspar in matrix of feldspar, chlorite and iron oxide minerals. Mt. Rowe section; sample No. CC-28. Magnification X10. Plan polarized light.

Figure 2: Purcell lava fm.--Microporphyritic plagioclase feldspar in chloritic matrix. Skookumchuck Creek section; sample No. SC-22. Magnification X10. Plane polarized light.

Figure 3: Purcell lava fm.--Olivine and pyroxene morphs enclosed by plagioclase feldspar phenocrysts. Roosville section; sample No. G-11. Magnification X10. Plane polarized light.

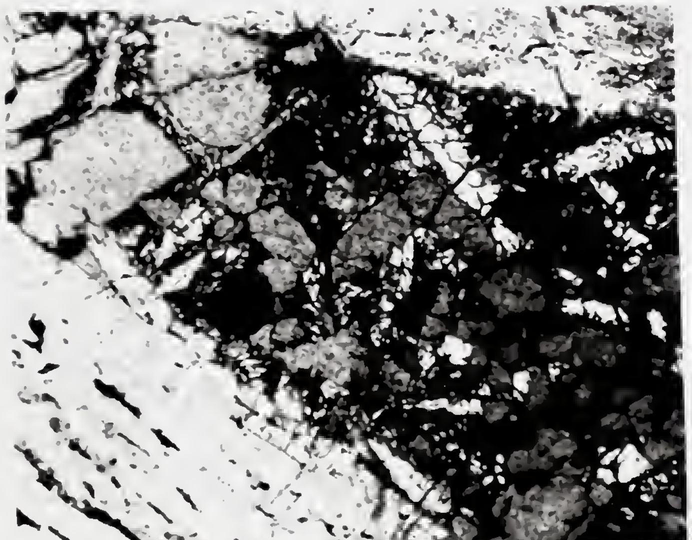
Figure 4: Diabase flow.--Titaniferous augite interstitial to plagioclase feldspar. Ruby Ridge section; sample No. RR-4. Magnification X50. Plane polarized light.

Figure 5: Purcell lava fm.--Amygdule infilled with chlorite and barite. Plagioclase laths aligned parallel to boundary of amygdule. Castle River section; sample No. CR-5. Magnification X10. Plane polarized light.

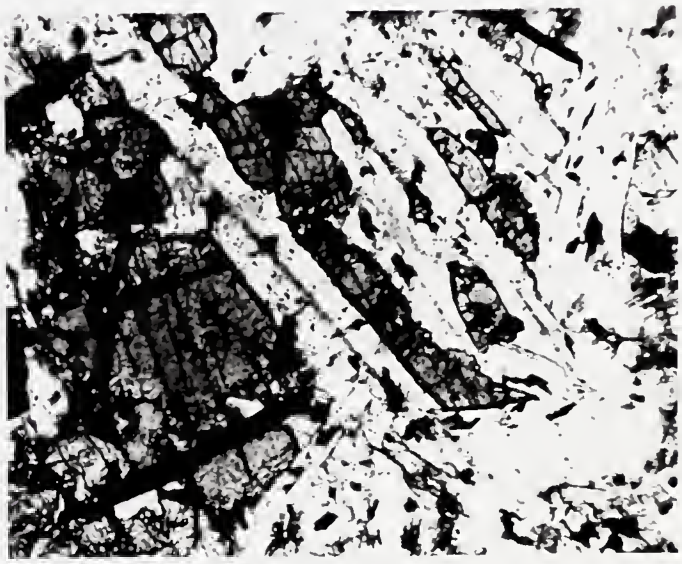
Figure 6: Purcell lava fm.--Highly altered plagioclase feldspar and a few olivine morphs. Lussier River section; sample No. LR-13. Magnification X10. Plane polarized light.

1.

2.

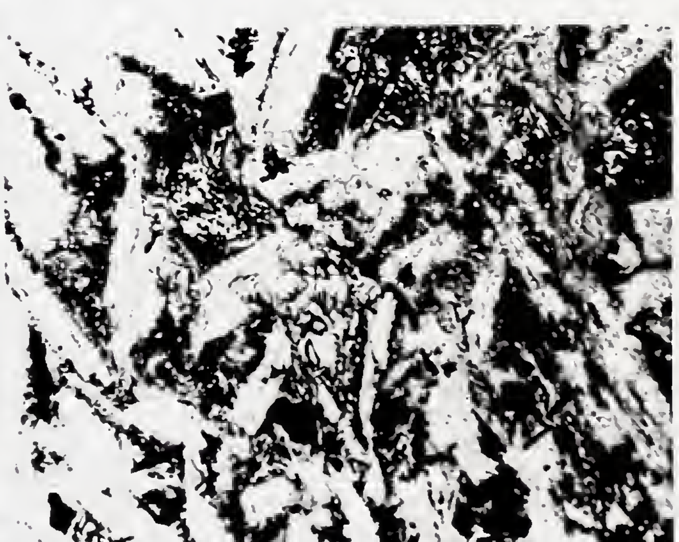


3.



4.

5.



6.

PLATE 3

EXPLANATION OF PLATE 4

Photomicrographs of Thin Sections

Figure 1: Diabase sill.--Radiating intergrowth of plagioclase feldspar and quartz in a granophyric texture. St. Mary Lake section; sample No. SM-12. Magnification X80. Crossed nicols.

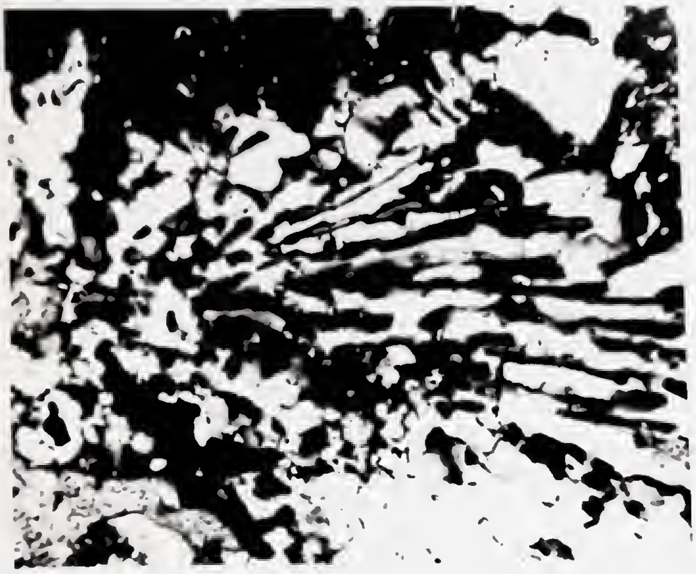
Figure 2: Diabase sill.--Cunieform type of granophyre with orthoclase and quartz. Logan Pass, Montana; sample No. 2999. Magnification X80. Crossed nicols.

Figure 3: Granite stock.--The main minerals are muscovite, plagioclase, quartz and tourmaline. Hellroaring Creek, B.C.; sample No. HR-36. Magnification X10. Crossed nicols.

Figure 4: Diabase sill and Siyeh fm.--Chilled lower margin of sill with pyroxene and olivine phenocrysts. Knife-edge contact with very fine-grained calc flintas. Lake Alderson, Alta.; sample No. 3176. Magnification X10. Plane polarized light.

Figure 5: Diabase sill.--Amphibole with rosette texture in groundmass of quartz and plagioclase. Irishman Creek section; sample No. IR-24. Magnification X10. Plane polarized light.

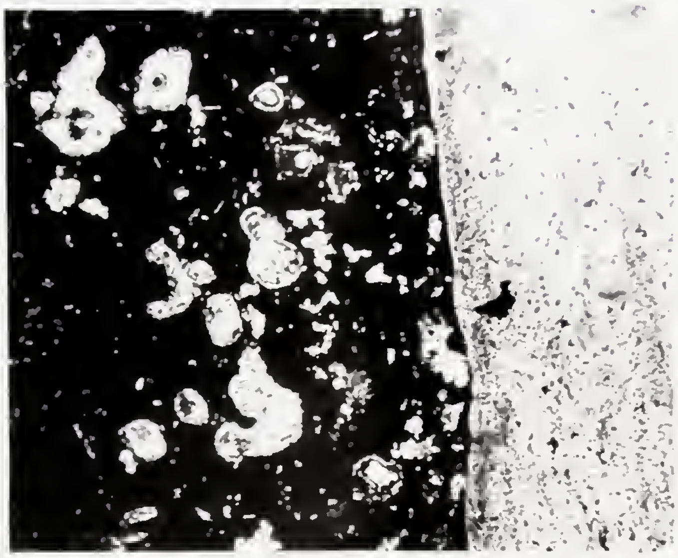
Figure 6: Aldridge fm.--Poikiloblastic amphibole in matrix of biotite, quartz and plagioclase. Irishman Creek section; sample No. IR-2. Magnificiation X10. Plane polarized light.



1.

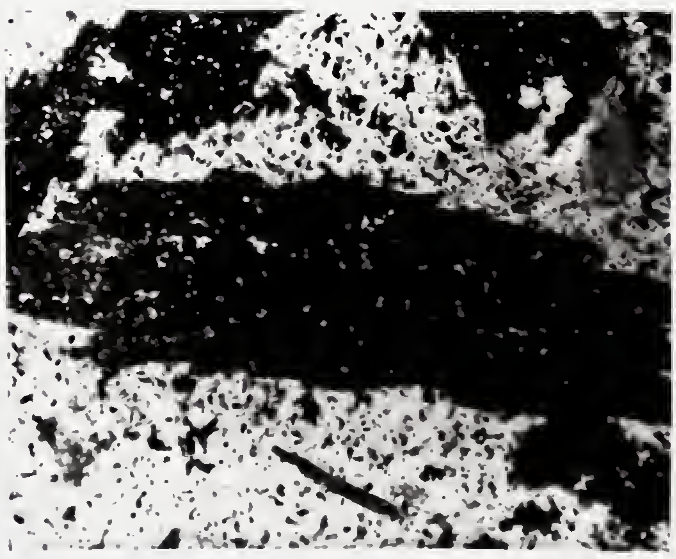
2.

3.



4.

5.



6.

PLATE 4

EXPLANATION OF PLATE 5

Photomicrographs of Thin Sections

Figure 1: Magnetite forms the outline of a relict olivine grain. Chlorite infills the skeletal framework of the magnetite. Roosville section; sample No. G-6. Magnification X80. Plane polarized light.

Figure 2: Magnetite outlines a former olivine grain. Skookumchuck Creek section; sample No. SC-27. Magnification X80. Plane polarized light.

Figure 3: A relict olivine grain is outlined by magnetite. Serpentine is present in the pseudomorph. Blakiston Brook section; sample No. W-17. Magnification X80. Plane polarized light.

Figure 4: Olivine morph surrounded by plagioclase feldspar. Blakiston Brook section; sample No. W-17. Magnification X80. Plane polarized light.

Figure 5: Olivine morph marked by magnetite. Gold Creek section; sample No. GC-4. Magnification X80. Plane polarized light.

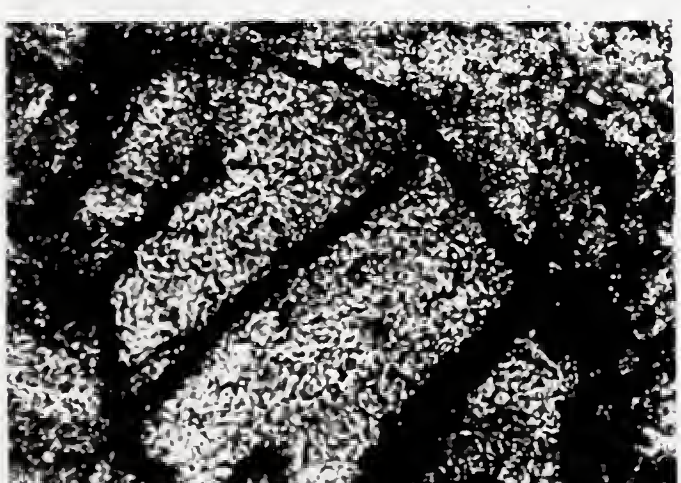
Figure 6: Olivine morph outlined by magnetite. Mt. Rowe section; sample No. CC-24. Magnification X80. Plane polarized light.

1.

2.

3.

4.



5.

6.

PLATE 5

EXPLANATION OF PLATE 6

Photomicrographs of Thin Sections

Figure 1: Highly altered and fractured plagioclase phenocryst in a matrix of chlorite and small feldspar grains. Lussier River section; sample No. LR-18. Magnification X10. Crossed nicols.

Figure 2: Euhedral biotite phenocrysts rimmed with deep red-brown borders. Minette dyke; sample No. SC-25. Magnification X10. Plane polarized light.

Figure 3: Fresh flake of muscovite in a matrix of quartz and feldspar. Hellroaring Creek; sample No. HR-36. Magnification X10. Crossed nicols.

Figure 4: Twinned plagioclase surrounded by quartz and amphibole grains. St. Mary Lake; sample No. SM-9. Magnification X80. Crossed nicols.

Figure 5: Radiating amphiboles in a groundmass of quartz and feldspar. Irishman Creek section; sample No. IR-25. Magnification X10. Plane polarized light.

Figure 6: Relict amphibole grain replaced by chlorite and biotite. Irishman Creek section; sample No. IR-3. Magnification X50. Plane polarized light.

NOTE: Figures 2, 3, 5 and 6 are photomicrographs of minerals used for physical age determinations.

Figure 7: Chlorite interstitial to plagioclase feldspar. Roosville section; sample No. G-11. Magnification X10. Plane polarized light.

Figure 8: Relict amphibole grain replaced by chlorite and magnetite. Lake Alderson; sample No. 3176. Magnification X80. Plane polarized light.

Figure 9: Small pseudomorph of olivine in centre of picture. Logan Pass section; sample No. LP-3. Magnification X10. Plane polarized light.

Figure 10: Tuff with sedimentary and volcanic constituents. Lussier River section; sample No. LR-15. Magnification X10. Plane polarized light.

Figure 11: Volcanic rock fragments in tuffaceous rocks. Roosville section; sample No. G-8. Magnification X10. Plane polarized light.

Figure 12: Volcanic rock fragments with a microporphyritic plagioclase phenocryst in a dark aphanitic matrix. Gold Creek section; sample No. GC-5. Magnification X80. Plane polarized light.

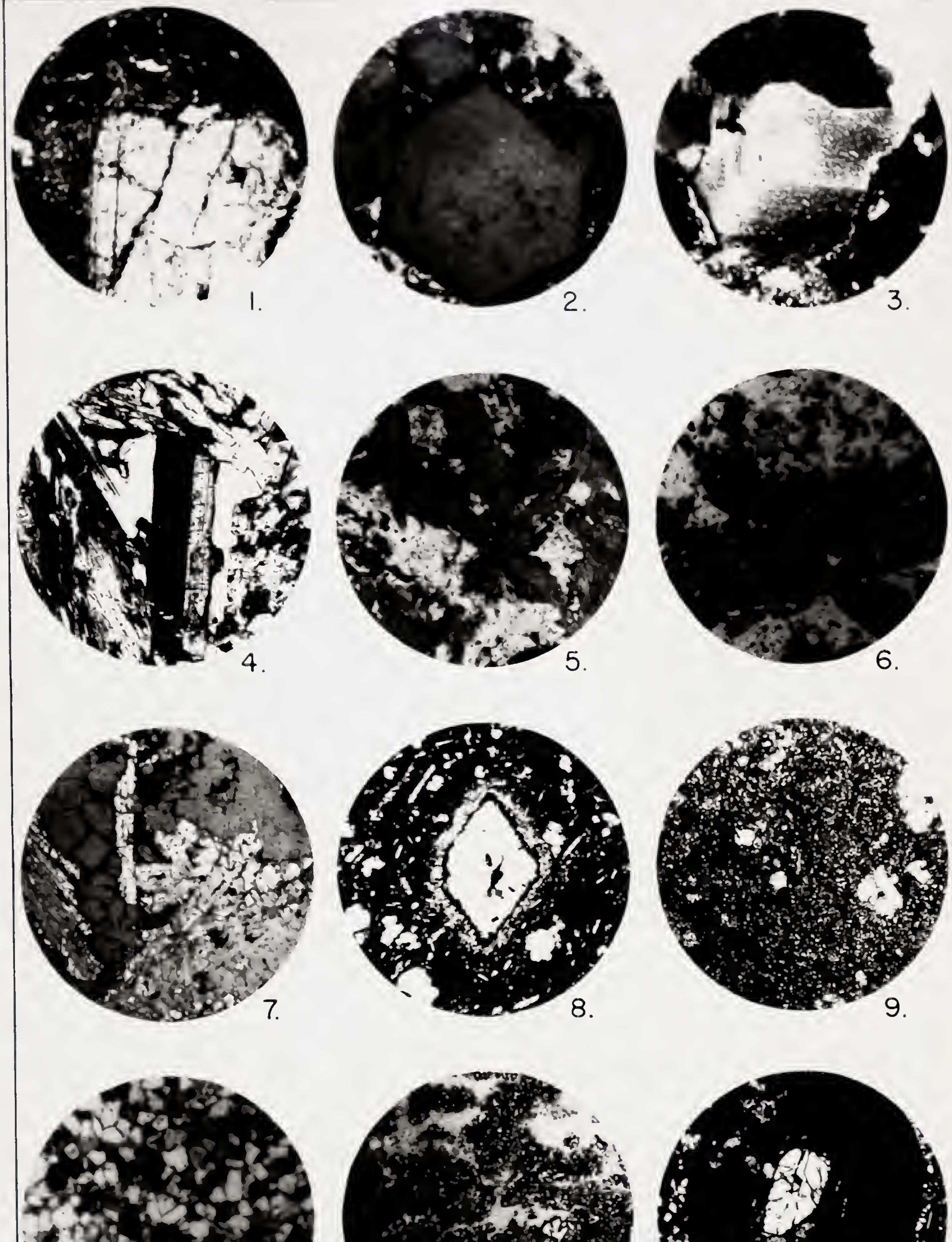


PLATE 6